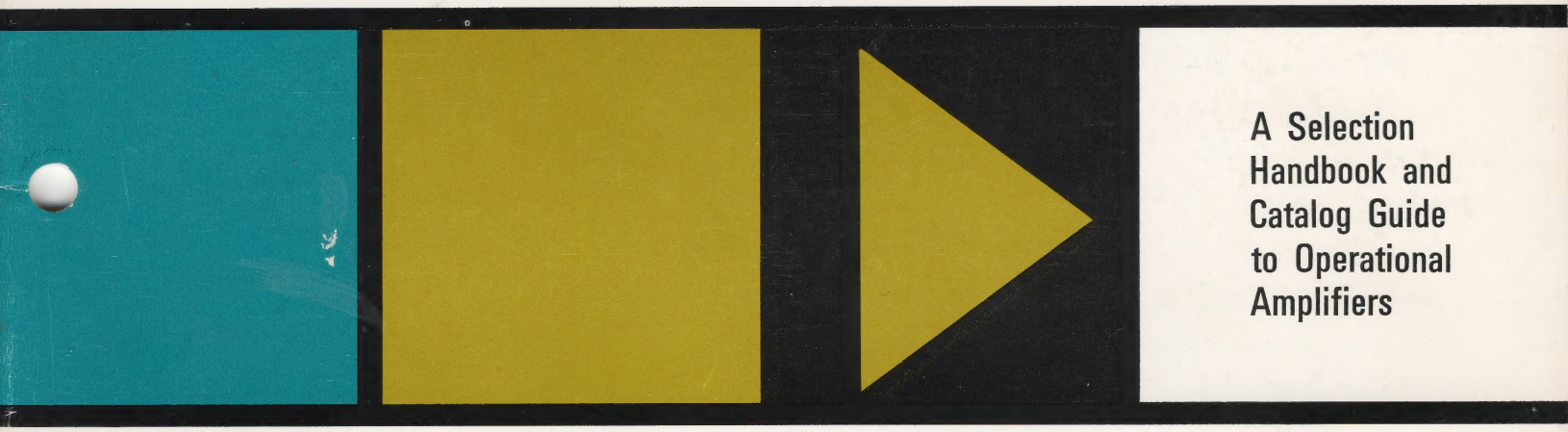
ANALOG



DEVICES

A Selection Handbook and Catalog Guide to Operational Amplifiers

January 1969

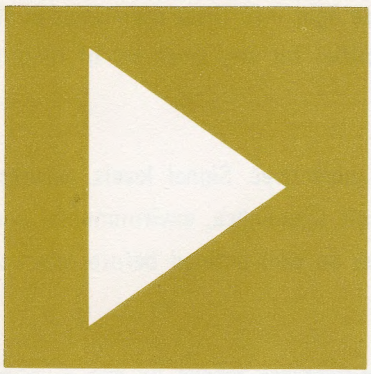
Table of Contents

How to select operational amplifiers	2
Featured products	8
Specifications	16
Military qualified/custom design products	24
Reference drawings	25
Bibliography of op-amp literature	31
Applications engineering services	32

OPERATIONAL AMPLIFIERS
ANALOG MULTIPLIERS
FUNCTION MODULES
POWER SUPPLIES
ACTIVE FILTERS

The year just ended has seen operational amplifier technology continue its dramatic growth. The main focus of attention has been on the almost feverish price reductions of integrated circuit operational amplifiers. Simultaneously, discrete and hybrid manufacturers have continued to develop better devices which are suitable for more sophisticated applications.

At Analog Devices, new circuit techniques were evolved in 1968 based on a number of new, improved components which have become available at lower cost. In view of these developments, we have made a careful review of our entire product line, and as a result we are proud to introduce 19 brand new products in our 1969 catalog. The primary emphasis in these new product designs is *greater user value*; that is, better performance at lower cost. The objective is to make our modular op-amps a practical and economical choice in a broad range of sophisticated applications.



These three examples illustrate the degree to which we have succeeded:

Model 232 – a chopper stabilized op-amp with ±.25μV/°C drift. Priced at $54. in 100 lots, this amplifier costs less than half that of comparable units available last year.

Model 310 – a new varactor bridge amplifier with only 0.01 picoamps bias current and 30μV/°C voltage drift. This unit represents a break-through in both price and performance. The $50 quantity price makes this solid state device an attractive alternative to vacuum electrometer tubes.

Model 118 – a general purpose op-amp with performance a step up from integrated circuits. Gain of 250,000, slew rate of 6V/μsec and bias current of 0.6nA/°C makes the 118 a real bargain at $11. unit cost.

It is apparent now that there is a definite and continuing need for companies like Analog Devices, which specialize in hybrid and discrete component amplifiers. That is, although linear monolithic circuits are most economical in simple circuits, the performance of IC op-amps available now and in the forseeable future just will not meet the requirements of many applications. Moreover, custom designed and special purpose op-amps are not attractive to the larger semiconductor companies even though the requirements may be well within their technical capability.

In addition to new product innovations, we strive to maintain an application engineering service of extremely high calibre, and continue to publish the most accurate and comprehensive technical literature and application notes possible in support of our products.

Analog Devices' continued objective is one of clear technical leadership in this exciting and progressive technology. Thank you for your interest in our products and our company.

Ray Stata

Ray Stata/Vice-President

HOW TO SELECT OPERATIONAL AMPLIFIERS

With the almost overwhelming proliferation of operational amps in recent years, the *selection* of the most appropriate device for a given application has become almost an art.

The designer faced with choosing from among the literally hundreds of models available may well be bewildered by the almost incredible choice of devices available, and the problem becomes even more complex by the realization that op-amps can be properly characterized by no less than about 25 separate specifications. Interpretation of the specifications adds yet another dimension to the task which is further clouded by the fact that there is virtually no standardization of specification definitions among various manufacturers. This last problem is particularly acute with reference to comparisons made between discrete component operational amplifiers and linear monolithic integrated circuit amplifiers.

Still, the designer who would avail himself and his company of the almost fantastic capabilities of these most sophisticated components must cut through the maze.

There are two "keys" vital to the selection of the right device for a specific application; and the purpose of this section is to shed some light into these sometimes dimly lit corners. To properly choose an operational amplifier for any given set of requirements, the designer must have:

1. A complete definition of the design objectives. Signal levels, accuracy desired, bandwidth requirements, circuit impedance, environmental conditions and several other factors must be well defined before selection can be effectively undertaken.

2. Firm understanding of what the manufacturer means by the numbers published for the parameters. It is a fundamental pitfall in op-amp selection to assume that any two manufacturers mean the same thing by the published numbers defining any given parameter, no matter how alike the data sheets may appear. In most cases, (but by no means all) the manufacturer is honest and has given you valuable information. It must be "decoded" however, in terms meaningful to your requirements and this requires a knowledge of how the terms are defined.

In the five pages which follow, we shall endeavor to:

A. Develop a kind of "checklist" about your application which assures that all significant factors are taken into account.

B. Provide meaningful definitions for each of our published specifications.

C. Illustrate how the requirements of your design are "translated" in terms of these specifications, and from there to an effective and economical choice.

We also hope to instill confidence that Analog Devices is a good company with which to do business. We are a company with integrity, technical competence, and a genuine interest in helping you to the proper and profitable use of operational amplifiers and related devices.

APPLICATION CHECKLIST

By way of an application "checklist," the designer will need to account for the following:

1) Character of the application
   The character of the application (inverter, follower, differential amplifier, etc.) will often influence the choice of amplifier. Chopper stabilized amplifiers, for example, are not generally applicable where differential inputs are required.

2) Accurate description of the input signal
   It is extremely important that the input signal be thoroughly characterized. Is the input a voltage source or current source? Range of amplitude? Source impedance? Time/frequency characteristics?

3) Environmental conditions
   What is the maximum range of temperature, time, and supply voltage over which the circuits must operate (to the required accuracy) without readjustment?

4) Accuracy desired
   The accuracy requirement determines the extent to which the foregoing considerations are critical, and ultimately points the way to a device (or series of devices) which are acceptable. Accuracy must, of course, be defined in terms meaningful to the application with regard to bandwidth, DC offset, etc.

SELECTION PROCESS

In general, the objective of amplifier selection should be to choose the least expensive device which will meet the physical, electrical, and environmental requirements imposed by the application. This suggests that a "Low Cost/Moderate Performance" amplifier (as shown on Pages 9 and 17) will be the best choice in all applications where the desired performance requirements can be met.

Where this is not possible, it is generally because of limitations encountered in two areas: 1) Bandwidth Requirements, and/or 2) DC Offset and Drift Parameters.

Bandwidth

Although all selection criteria must be met simultaneously, determination of the bandwidth requirements is a logical starting point because:

A) If DC information is not of interest, a suitable blocking capacitor may be connected at the amplifier input and all of the "drift" specifications may be ignored, and secondly,

B) Where high frequency (>10MHz) characteristics are of primary importance, the choice will be limited to those amplifiers designated "Wideband/Fast Response" and listed on Page 19.

Where DC information is required and where frequency requirements are relatively modest (full power response below 100kHz, unity gain of less than 1.5MHz) other criteria will probably influence the final choice. It is important, however, to choose an amplifier with which an adequate value of loop gain is assured (at the maximum frequency of interest) to obtain the desired accuracy. Loop gain is the excess of open loop gain over closed loop gain, and is responsible for the diminishing error due to fluctuations in the open loop gain due to time, temperature, etc. As a rule of thumb, loop gain of 100 will yield error of no more than 1%, 0.1% from loop gain of 1000, etc. Open loop gain characteristics for all amplifiers appear on Page 25. Where undistorted response is required, the specifications for full linear response and slewing rate should be chosen such that they are not exceeded at the highest frequency of operation.

Offset and Drift Considerations

In what is by far the majority of op-amp applications, final selection is determined by the DC offset and drift characteristics. To undertake amplifier selection in these cases, it is necessary to "translate" the requirements listed above as follows:

1) What input impedance must the circuit present to the signal source?

This depends primarily on the source impedance, R_S, and the amount of loading error which is acceptable. Most amplifier circuits are designed around either the inverting or noninverting circuit of Figure 1. The choice is often made between the two to accommodate the impedance requirement. Input impedance for the inverting circuit is approximately equal to the summing impedance, R_i, and the upper limit on the magnitude of R_i is determined by the allowable drift error because of input bias current as discussed below. The noninverting circuit offers inherently higher input impedance than the inverting circuit (due to "bootstrapping" feedback) and in this case input impedance is approximately equal to the common mode impedance of the amplifier, R_{CM}.

2) How much drift error can be tolerated?

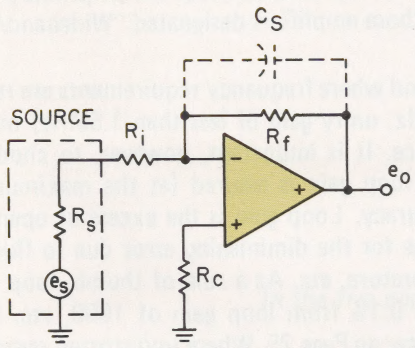
The question is related to the input signal level, e_s, and the required accuracy. For example, to amplify or otherwise manipulate a DC input signal of one volt with an accuracy of 0.1%, the offset drift error, V_d, must be one millivolt or less. (This assumes that other sources of error such as input loading, noise and gain error have already been allowed for.) By the same reasoning, the allowable drift error for a 1 volt signal and 0.01% accuracy would be 100μV.

When this has been defined, the allowable limits of offset voltage (e_{os}), bias current (i_b), and difference current can be calculated by the equations of Figure 1.

Figure 1 gives the equations which relate offset voltage (e_{os}), bias current (i_b), difference current (i_d) and the external circuit impedances to the drift error, V_d, for both the inverting and the noninverting circuits. From these equations it can be seen how the input impedance requirements of the foregoing paragraphs are related to the drift error. For example, in the case of the inverting circuit, an offset error voltage, i_bR_i, is generated by the bias current flowing through the summing impedance. This error increases for increasing R_i. Since R_i also sets the input impedance there is a conflict between high input impedance and low offset errors. Likewise, for a given offset error, higher values for R_i can be used with an amplifier which has lower bias current. Where it will otherwise function properly, the noninverting circuit generally makes a better choice for high input impedance circuits. Also, for the same source and input impedance requirement, a given amplifier will generate lower offset errors for the noninverting circuit than for the inverting circuit. This is so because the bias current flows only through R_S for the noninverter and this will always be less than the input impedance, R_i, of the inverter. Input impedance of the noninverter (approximately R_{cm}) is typically 10^7 ohms even for the least expensive amplifiers and up to 10^{11} ohms for FET types. Unfortunately, however, the noninverting configuration cannot always be used since it will not perform many circuit functions such as integration or summation. A further limitation occurs in high accuracy applications, where common mode errors may rule out this circuit configuration.

Initial offsets can usually be zeroed at room temperature so that only the maximum temperature excursion (ΔT) from 25°C need be considered. For example, over the range of −25 to +85°C, the maximum temperature excursion (ΔT) from 25°C would be 60°C.

As a practical matter offset errors due to supply voltage and time drift can generally be neglected since errors due to temperature drift are usually much greater.



$$e_o = -\frac{R_f}{R_i}\left[e_s + e_{os}\left(\frac{R_f+R_i}{R_f}\right) + i_b R_i\right] \quad \text{FOR } R_C = 0 \text{ AND } R_S \ll R_i$$

Signal Input drift error − V_d

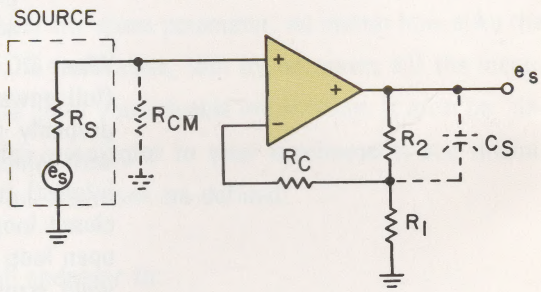
$$e_o = -\frac{R_f}{R_i}\left[e_s + e_{os}\left(\frac{R_f+R_i}{R_f}\right) + i_d R_i\right] \quad \text{FOR } R_C = R_i R_f / R_i + R_f \text{ AND } R_S \ll R_i$$

Signal Input drift error V_d

INPUT IMPEDANCE $R_{IN} \approx R_i$

$$\%\ \text{DRIFT ERROR} = \frac{100\,V_d}{e_s}$$

FIGURE 1A. INVERTING CONFIGURATION.



$$e_o = \frac{R_2+R_1}{R_1}\left[e_s + e_{os} + i_b R_s\right] \quad \text{FOR } R_C = 0$$

Signal Drift error − V_d

$$e_o = \frac{R_2+R_1}{R_1}\left[e_s + e_{os} + i_d R_s\right] \quad \text{FOR } R_C = R_S - \frac{R_1 R_2}{R_1 + R_2}$$

Signal Drift error V_d

INPUT IMPEDANCE $R_{IN} \approx R_{CM}$

$$\%\ \text{DRIFT ERROR} = \frac{100\,V_d}{e_s}$$

FIGURE 1B. NONINVERTING CONFIGURATION.

DEFINITION OF SPECIFICATIONS

OPEN LOOP GAIN	
dc, rated load, min	5×10^5
RATED OUTPUT, min	±10V @ 20mA

OPEN LOOP GAIN

Open loop gain, A, is defined as the ratio of output voltage to error voltage between the amplifier inputs. Gain is usually specified only at DC (A_O), but in many applications the frequency dependence of gain is also important. For this reason the typical open loop gain response is published for each amplifier, and appears on page 25.

RATED OUTPUT

Rated output voltage is the minimum peak output voltage which can be obtained at rated output current before clipping or excessive non-linearity occurs. Rated output current is the minimum guaranteed value of current supplied at the rated output voltage. Load impedance less than E_O/I_O can be used but E_O will decrease, distortion may increase and open loop gain will be reduced. (All models are short circuit protected.)

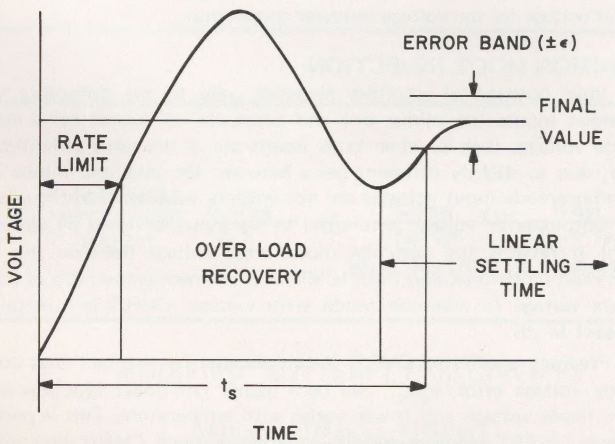
ABOUT SETTLING TIME

Although settling time does not appear in the specification charts, it is increasingly important as operational amplifiers find application in high speed data systems. Settling time is defined as the time elapsed from the application of a perfect step input to the time when the amplifier output has entered and remained within a specified error band symmetrical about the final value.

Settling time, therefore, includes the time required for the amplifier to slew from the initial value, recover from slew rate limited overload, and settle to a given error in the linear range.

Because settling time is determined by a combination of amplifier characteristics (both linear and non-linear), and because it is a closed loop parameter, it cannot be readily predicted from the open loop specifications such as slew rate, small signal bandwidth, etc.

Analog Devices specifies settling time for the condition of unity gain, relatively low impedance levels, and no capacitive loading. A full-scale step input is used to determine settling time and the step is generally unipolar, i.e. from zero to plus or minus full scale. The settling time indicated is generally the longest time resulting from a step of either polarity and is given as a percentage of the full scale step transition.



TYPICAL SETTLING TIME CHARACTERISTICS

FREQUENCY RESPONSE		
Unity gain, small signal	500kHz	50
Full power response, min	2kHz	2
Slew rate, min	.12V/μsec	.1
Overload recovery	5msec	

UNITY GAIN SMALL SIGNAL RESPONSE

Unity gain small signal response, f_t, is the frequency at which the open loop gain becomes unity or zero dB. "Small signal" indicates that in general it is not possible to obtain large output voltage swing at high frequencies because of distortion due to slew rate limiting or signal rectification. For amplifiers with symmetrical response on each input, f_t may be obtained by either the inverting or non-inverting configurations. Some wideband amplifiers with feed forward design have fast response only on the negative input which restricts high speed use to the inverting circuit.

FULL POWER RESPONSE

The large signal and small signal response characteristics of operational amplifiers differ substantially. An amplifier will not respond to large signal changes as fast as the small signal bandwidth characteristics would predict, primarily because of slew rate limiting in the output stages. We specify full power response in two ways: Full linear response and full peak response.

Full linear response, f_p, is the maximum frequency at unity closed loop gain, for which a sinusoidal input signal will produce full output at rated load without exceeding pre-determined distortion level. Note that this specification does not relate to "response" in the sense of gain reduction with frequency but refers only to distortion in the output signal. There is no industry wide accepted value for the distortion level which determines the full linear response limitation but we use 3% as a maximum acceptable limit. One subtle point here is that in many applications the distortion which is caused by exceeding the full linear response can be comfortably ignored. But a far more serious effect, often overlooked, is that a DC offset voltage can be generated when the full linear response is exceeded. This is due to rectification of the asymmetrical feedback waveform or overloading the input stage with large distortion signals at the summing junction.

Certain amplifiers designed to optimize high frequency performance will provide full output swing substantially beyond the full linear response (3% distortion) limit described above. Since linear waveshape is not generally a consideration in the use of these devices, they are specified to the maximum frequency at which they will produce full output swing. This is termed "full peak response" and is indicated as such on the specification charts by the word "peak" in the row marked Full Power Response.

SLEWING RATE

Slewing rate, S, usually expressed in volts/μsec, defines the maximum rate of change of output voltage for a large input step change.

OVERLOAD RECOVERY

Overload recovery, τ, defines the time required for the output voltage to recover to the rated output voltage E_O from a saturated condition. In some amplifiers the overload recovery will increase for large impedances (greater than 50kΩ) in the input circuit. Published specifications apply for low impedances and assume that overload recovery is not degraded by stray capacitance in the feedback network. Overload recovery is defined for 50% overdrive.

DEFINITION OF SPECIFICATIONS

INPUT OFFSET VOLTAGE @ 25°C, max	Adj to 0			A
Average vs. temp 10 to 60°C, max, μV/°C♦				
–25 to 85°C, max, μV/°C♦	±15	±10	±5	±20
vs. supply	±20μV/%			
vs. time	±100μV/mo			
INPUT BIAS CURRENT @ 25°C, max	±2nA			
Average vs. temp 10 to 60°C, max, nA/°C				
–25 to 85°C, max, nA/°C	±.15nA/°C			
INPUT DIFFERENCE CURRENT @ 25°C	±2nA			
Average vs. temp 10 to 60°C, nA/°C				
–25 to 85°C, nA/°C	±.05nA/°C			
INPUT IMPEDANCE				
Differential	4MΩ			
Common mode	500MΩ			
INPUT NOISE				
Voltage .01Hz to 1Hz p-p	2μV			
5Hz to 50kHz rms	4μV			
Current .01Hz to 1Hz p-p	30pA			
INPUT VOLTAGE RANGE				
Absolute max. differential	±15V			
Common mode voltage	>10V			
Common mode rejection	10,000 @ ±10			

INITIAL OFFSET VOLTAGE

Offset voltage, e_{os}, is defined as the voltage required at the input from a zero source impedance to drive the output to zero. Initial offset voltage, E_{os}, defines the offset voltage at 25°C and rated supply voltages. In most amplifiers, provisions are made to adjust initial offset to zero with an external trim potentiometer.

DRIFT VS. SUPPLY

Offset voltage, bias current and difference current vary as supply voltage is varied. Usually errors due to this effect are negligible compared to temperature drift.

DRIFT VS. TIME

Offset voltage, bias current and difference current change with time as components age. It is important to realize that the published time drift for amplifiers does not accumulate linearly. For example, voltage drift for a chopper stabilized amplifier (which is by far the best amplifier type for long term stability) might be quoted as 1μV/day whereas cumulative drift over 30 days would not exceed 5μV nor 15μV in a year. In general the drift accumulation may be extrapolated by multiplying the specified drift/day by the *square root* of the number of days. Since our catalog specifies drift/month, divide by $\sqrt{30}$ or 5.5 to obtain drift/day.

INITIAL BIAS CURRENT

Bias current, i_b, is defined as the current required at either input from an infinite source impedance to drive the output to zero (assuming zero common mode voltage). For differential amplifiers, bias current is present at both the negative and positive inputs. All Analog Devices specifications pertain to the worst of the two (not average or mean). For single ended amplifiers, bias current refers to the current at the negative input only.

Initial bias current, I_b, is the bias current at either input measured at 25°C, rated supply voltages and zero common mode voltage. The designation (0,+) or (0,–) indicates that no internal compensation has been used to reduce initial bias current and hence the polarity is always known. The sign indicates to which power supply voltage an external compensating resistor should be connected to zero the initial bias current. The designation (±) indicates that internal compensation has been used to reduce initial bias current and that the residual bias current may be of either polarity. In general, compensating initial bias current has little effect on the bias current temperature coefficient. One should note that the bias current of FET amplifiers increases by a factor of 2 for each 10°C rise in temperature.

INITIAL DIFFERENCE CURRENT

Difference current, i_d, is defined as the difference between the bias currents at each input. The input circuitry of differential amplifiers is generally symmetrical so that bias current at each input tends to be equal and tends to track with changes in temperature and supply voltage. Therefore, difference current is about .1 times the bias current at either input, assuming that initial bias current has not been compensated.

INPUT IMPEDANCE

Differential input impedance, R_d, is defined as the impedance between the two input terminals, measured at 25°C, assuming that the error voltage e_ϵ is nulled or very near zero volts. To a first approximation, dynamic impedance can be represented by a capacitor, C_d, in parallel with R_d.

Common mode impedance, R_{cm}, is defined as the impedance between each input and ground (or power supply common) and is specified at 25°C. For most circuits common mode impedance on the negative input $R_{cm}-$, has little significance except for the capacitance which it adds to the summing junction. However, common mode impedance on the plus input, $R_{cm}+$, sets the upper limit on closed loop input impedance for the non-inverting configuration. Dynamic impedance can be represented by a capacitor, C_{cm}, in parallel with R_{cm} which usually runs from 5 to 25pF on the plus input.

Common mode impedance is a non-linear function of both temperature and common mode voltage. For FET amplifiers common mode impedance is reduced by a factor of two for each 10°C temperature rise.

As a function of a common mode voltage R_{cm} is defined as average impedance for a common mode voltage change from zero to $\pm E_{cm}$, that is, maximum common mode voltage. Incremental R_{cm} about some large common mode voltage may be considerably less than the specified average R_{cm}, especially for FET input amplifiers.

INPUT NOISE

Input voltage and current noise characteristics can be specified and analyzed very much like offset voltage and bias current characteristics. In fact, drift can be considered noise which occurs at very low frequencies. The primary difference in measuring and specifying noise as opposed to DC drift is that bandwidth must be considered. At low frequencies, 100Hz or less, 1/f noise prevails which means that the noise per root cycle increases inversely with frequency. At the mid-band frequencies noise per root cycle is constant or "white".

For this reason two noise specifications are given. Low frequency noise in a bandpass of .01 to 1Hz is specified as peak to peak with a 3.3σ uncertainty, meaning that 99.9% of the observed peak to peak exclusions will fall within the specified limits. Wideband noise in a bandpass of 5Hz to 50kHz is specified as rms.

ABSOLUTE MAXIMUM DIFFERENTIAL

Under most operating conditions, feedback maintains the error voltage between inputs to a very near zero volts. However, in some applications, such as voltage comparators, the voltage between inputs can become large. E_d defines the maximum voltage which can be applied between inputs without causing permanent damage to the amplifier.

MAXIMUM COMMON MODE VOLTAGE

For differential input amplifiers, the voltage at both inputs can be raised above ground potential. Common mode voltage, E_{cm}, is defined as the voltage (above ground) when both inputs are at the same voltage. E_{cm} is defined as the maximum peak common mode voltage which will produce less than a 1% error at the output. E_{cm} establishes the maximum input voltage for the voltage follower connection.

COMMON MODE REJECTION

An ideal operational amplifier responds only to the difference voltage between inputs (e+ minus e–) and produces no output for a common mode voltage, that is, when both inputs are at the same potential. However, due to slightly different gains between the plus and minus inputs, common mode input voltages are not entirely subtracted at the output. If the output error voltage is referred to the input (dividing by closed loop gain) it reflects the common mode error voltage between the inputs. Common mode rejection ratio (CMRR) is defined as the ratio of common mode voltage to common mode error voltage. CMRR is sometimes expressed in dB.

Precisely specifying CMRR is complicated by the fact that common mode voltage error, $e_{\epsilon cm}$, can be a highly non-linear function of common mode voltage and it also varies with temperature. This is particularly true for FET input amplifiers. As a consequence, CMRR data published by Analog Devices are average figures assuming an end point measurement at the common mode voltage specified. The incremental CMRR about some large common mode voltage may be less than the average CMRR which is specified. Published CMRR specifications apply only to DC input signals. In general, CMRR becomes lower with increasing frequency.

TEMPERATURE DRIFT

Offset voltage, bias current and difference current all change or "drift" from their initial values with temperature. This is by far the most important source of error in most applications. The temperature coefficients of these parameters, $\Delta e_{os}/\Delta T$, $\Delta i_b/\Delta T$, and $\Delta i_d/\Delta T$ are all defined as the average slope over a specified temperature range. In general, however, drift is a non-linear function of temperature and the slopes are greater at the extremes of temperature than around normal (25°C) ambient.

Because of this non-linear characteristic, a definitive specification is only meaningful if the specification method is known. Ambiguity on this point can lead to some startling conclusions. For example, a rather popular method of specifying this extremely important parameter consists of: a) arithmetically subtracting the measured offset values at the upper and lower temperature extremes and b) dividing this difference by the temperature excursion. This can yield an extremely misleading result, particularly where offset drifts in the same direction at the two extremes. It is obviously possible to have *no* difference in the two end-point measurements, yet severe slopes may exist between the two as illustrated in Figure A. In this case the apparent (specified) drift would be *zero* $\mu V/°C$.

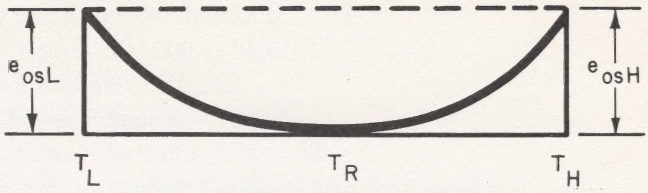


FIGURE A $\quad \frac{\Delta e_{os}}{\Delta T} = \frac{e_{osH} - e_{osL}}{T_H - T_L} = 0\mu V/°C$

Analog Devices employs two methods of drift specification — a "true butterfly" curve characteristic for the high performance/low drift models, and a "modified butterfly" for the lower cost amplifiers. Both overcome the deficiencies described above. A comparison of these methods is shown with definitive equations in Figure B. Essentially, the butterfly characteristic insures that if the amplifier is adjusted to zero at room temperature (T_r), the offset at any temperature would, in no case, exceed the value predicted by multiplying the specified drift rate (in $\mu V/°C$) by the temperature excursion. The amplifiers specified by the true butterfly are also listed. All other amplifiers in this catalog are specified by the "modified butterfly" technique.

BUTTERFLY CHARACTERISTICS

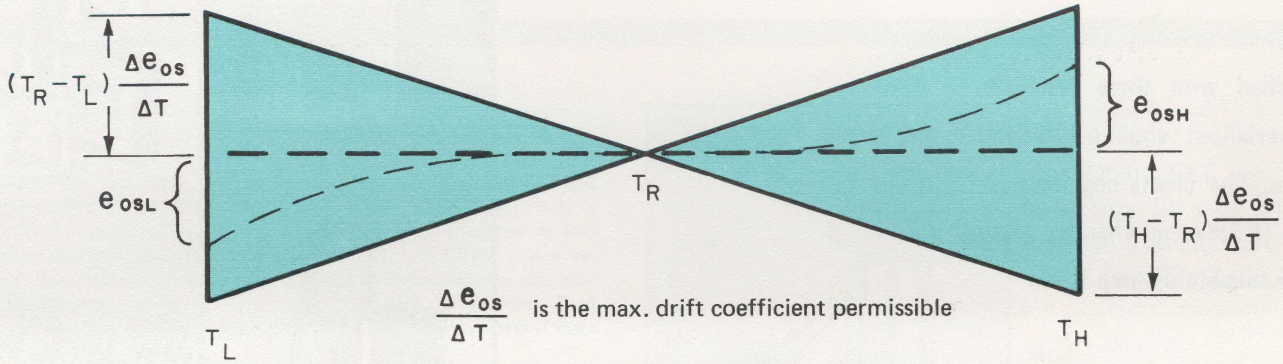


FIGURE B

ACTUAL SPECIFIED DRIFT $\quad \frac{\Delta e_{os}}{\Delta T} \leq \frac{e_{osH}}{T_H - T_R}$ OR $\frac{e_{osL}}{T_L - T_R}$

WHICHEVER IS LARGER

MODIFIED "BUTTERFLY" IS GIVEN BY

$$\frac{\Delta e_{os}}{\Delta T} = \frac{|e_{osH}| + |e_{osL}|}{T_H - T_L}$$

(This implies that the average $\Delta e_{os}/\Delta T$ from the reference temperature T_R to either extreme T_H or T_L will be no greater than twice the value obtained between the temperature extremes.)

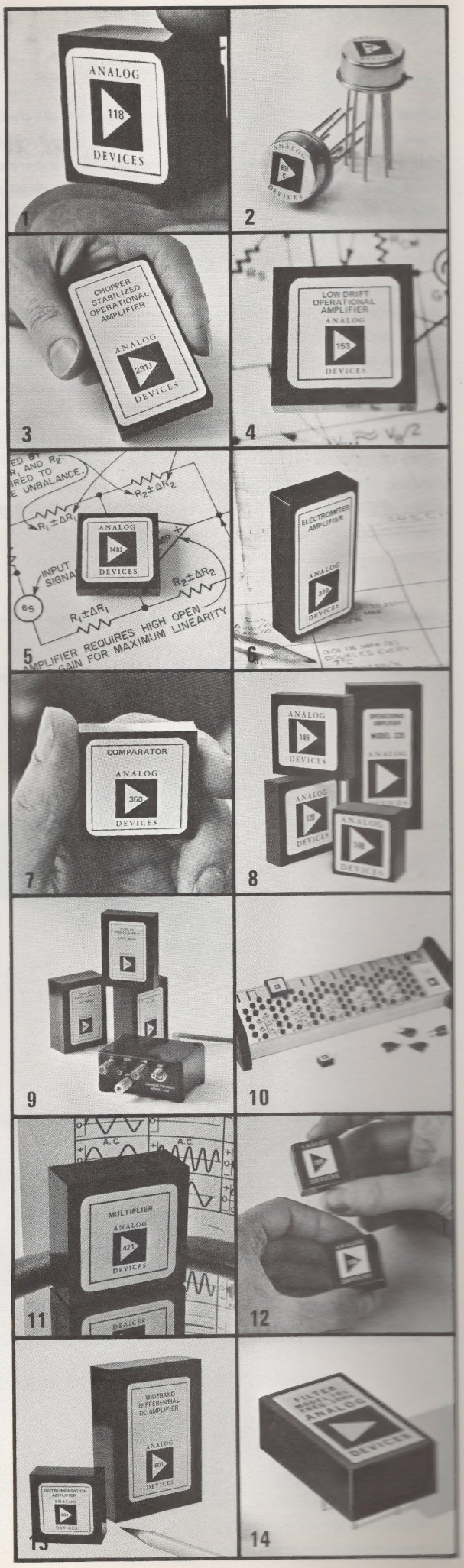
MODELS SPECIFIED BY TRUE BUTTERFLY

Model No.	Reference Page
143C	20
146	18,20
147C	19,20
149C	19
153	17
180	18
183	17,18
207	22
211/210	18,19
220	18,19
230	18
231	18
232	18

FEATURED PRODUCTS

The products on the following pages have been selected by our Applications Department for special emphasis because one or more of these devices are ultimately recommended in about 85% of all requirements with which we come in contact. For the most part they are new... in all cases they may be chosen with the designer's confidence that he is specifying a best buy... A product truly representative of today's state of the art. In general, if a satisfactory device can be found here it is not necessary to look further.

Although the majority of applications may be satisfied with these products many specialized requirements demand specialized hardware. The charts beginning on Page 16 list comprehensive specifications on our complete op-amp line.



Low Cost Op-Amps 1
Microcircuit Amplifiers 2
Chopper Stabilized Op-Amps 3
Low Voltage Drift Differentials 4
Low Bias Current FET Op-Amps 5
Ultra Low Bias Current Electrometers 6
FET Comparator Modules 7
Fast Settling Op-Amps 8
Power Supplies 9
Operational Manifolds 10
Analog Multipliers 11
Logarithmic Modules 12
Instrumentation Amplifiers 13
Active Filters 14

LOW COST OP-AMPS MODELS 118/119/165

Greater user value, (higher performance at lower cost), is the primary feature of this new generation of low cost operational amplifiers. New standards for the price/performance ratio of general purpose op amps have been achieved by a combination of improved circuit design, better components now available at lower cost and greater production efficiency.

The Models 118/119 and 165 are identical in design and performance except for variations in rated output voltage and current specifications. Important advantages of this new design are high open loop gain, fast slew rate, low bias current and immunity to thermal gradients.

VERSUS IC OP AMPS

Integrated circuit op amps are certainly the lowest cost solution to many problems. But there are many applications where the performance of ICs is just not adequate. The Model 118 was specifically designed as a low cost alternative to ICs where higher performance is required. It outperforms most IC op amps by at least an order of magnitude on all of the critical parameters. Other models in this series give ±20 volts and/or 20mA output options. All are internally compensated for 6dB/octave roll off.

VERSUS OTHER DISCRETE OP AMPS

At $11 unit price, the Model 118 will replace nearly all existing general purpose operational amplifiers with a substantial cost saving and significant improvement in performance as well. In addition to the obvious specification improvements, subtle benefits are achieved by the use of a dual input transistor. The close proximity of the junctions in the dual transistor minimizes offset errors due to thermal gradients, warm-up drift and self-heating. Low frequency noise due to thermal disturbances is also minimized.

COMPREHENSIVE SPECIFICATIONS APPEAR ON PAGES 17 AND 22

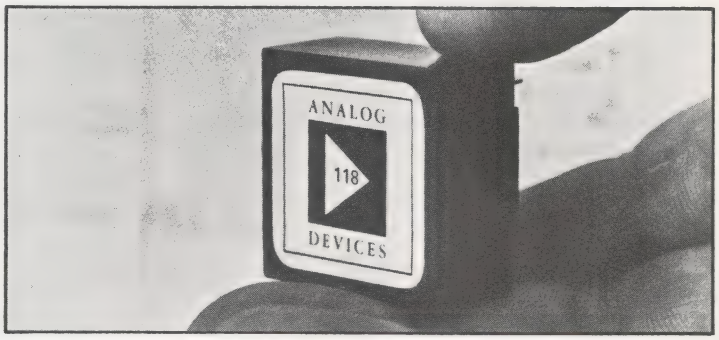
FEATURES

Low Cost – $11. (1–9) (Model 118A/K)
Low Bias Current – 0.5nA/°C
High Gain – 500,000 (119 A/K)
High Slew Rate - 6V/μsec
Full Power Response – 100kHz
Low Noise – 3μV rms (5Hz to 50kHz)
Immunity to Thermal Gradients with Dual Input Pair

SPECIFICATIONS

	118A/K	119A/K	165A/K
Open Loop Gain, min	2.5×10^5	5×10^5	2.5×10^5
Rated Output, min	±10V@5mA	±10V@20mA	±20V@5mA
Full Power Response, min	100kHz[1]	100kHz[1]	50kHz
Slew Rate, min	6V/μsec[1]	6V/μsec[1]	6V/μsec
Voltage Drift, max	±20/5μV/°C	±20/5μV/°C	±20/5μV/°C
Bias Current, max	±.6/.5nA/°C	±.6/.5nA/°C	±.6/.5nA/°C
Price (1-9)	$11./$21.	$24./$34.	$24./$34.

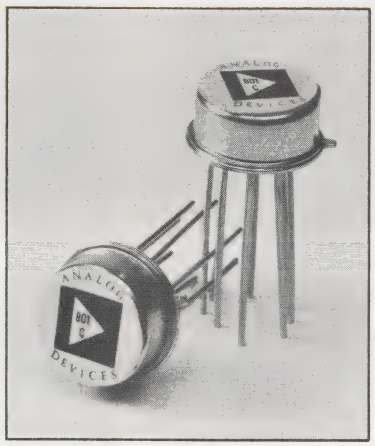
1. 20kHz and 1.2V/μsec for non-inverting operation.



MICROCIRCUIT AMPLIFIERS

Where small size and minimum weight are primary considerations, these microcircuit op-amps are likely to be the best choice. The Model P501 is a thin film hybrid type with an FET input stage. Fully compensated and self-contained, the P501 is actually smaller than IC amplifiers which require external compensation components. Input characteristics are outstanding. . .guaranteed maximum bias current of only 5pA, Input Z of 10^{11} ohms, and voltage drift as low as 25μV/°C. Unit quantity prices start at $30.

The 801 is a monolithic linear IC amplifier. A Darlington input configuration reduces input bias current to just 4nA, difference current drift guaranteed to be less than .02nA max (801 B). Open loop gain is somewhat reduced (to 15k) but is quite adequate for almost all applications. Otherwise, the 801 is identical with the "709" types, and is completely interchangeable in existing designs. The 801S is specified for operation over the full military temperature range of −55°C to +125°C.



FEATURES

Model P501, FET
Small Size, 0.6 x 0.6 x 0.25in.
Low Bias Current, 5pA max
Low Cost, $30 (Model A)

Model 801, IC
Low Bias Current, 4nA max
Low Current Drift, 0.02nA max
High Input Z, 25MΩ
Interchangeable with 709
100 Piece Price, $9.75 (801A)

COMPREHENSIVE SPECIFICATIONS APPEAR ON PAGES 17 AND 20.

	UNITS	801A	801B	709*	741*	LM101*	MC1539*
Bias Current, 25°C	nA	4	4	500	500	500	500
Over temp. range	nA	11	11	1500	1500	1500	700
Difference Current, 25°C	nA	2	1	200	200	200	60
Over temp. range	nA	8	2	500	500	500	75
Offset Voltage, 25°C	mV	5	5	5	5	5	3
Over temp. range	mV	7.4	5.6	6	6	6	4
Open Loop Gain	V/V	15K	15K	25K	25K	25K	50K
Input Impedance	MΩ	25	25	0.15	0.3	0.3	0.15
Price (100 lot)	$	9.75	13.00	6.60	7.00	8.80	7.50

*Published data July 1, 1968

FET HYBRID OP AMPS	P501A	P501B	P501C
Open Loop Gain, min	25k	25k	25k
Rated Output, min	±10V@5mA	±10V@5mA	±10V@5mA
Initial Offset Voltage, max	2mV	1mV	1mV
Voltage Drift, max	75μV/°C	25μV/°C	25μV/°C
Bias Current, max	25pA	10pA	5pA
Unity Gain Bandwidth	4MHz	4MHz	4MHz
Full Power Response, min	70kHz	70kHz	70kHz
Slewing Rate	3V/μsec	3V/μsec	3V/μsec
Price (1–9)	$30.	$35.	$50.

CHOPPER STABILIZED OP-AMPS

The 230 series sets new price standards for sophisticated chopper stabilized op amps. At $64. unit price, the Model 232 is less than one half the price of comparable units last year. Now OEM users will find it just as attractive to buy chopper stabilized op amps as they do the inexpensive differential types.

Performance of the 230 series has also been improved over previously available chopper amplifiers by using a new MOSFET chopper circuit. Long term drift tests indicate that initial offset voltage will stay within 5 microvolts indefinitely. Temperature drift of the "K" Model is less than an incredible 0.1μV/°C. Low frequency flicker noise, usually a limiting factor in chopper type designs, has been improved to 1.5μV peak to peak.

Three different models are offered: The Model 231 and 232, only 0.4" high for high density card file packaging, are the same except for output current of 20mA and 4mA respectively. The Model 230 is identical to the 232 except for a smaller volume package — 1.5" x 1.5" x 0.62".

Two versions of each model (J and K) allow you a selection of voltage and current drift performance.

	232J	232K
Open Loop Gain, min	10^7	10^7
Initial Offset Voltage, max	15μV	10μV
Offset Voltage Drift, max	.25μV/°C	0.1μV/°C
Long Term Stability	1μV/month	1μV/month
Voltage Noise, dc to 1Hz	1.5μV, p-p	1.5μV, p-p
Initial Bias Current, max	100pA	50pA
Bias Current Drift, max	1pA/°C	0.5pA/°C
Rated Output, min*	±10V@4mA	±10V@4mA
Price (1–9)	$64.	$99.

*Model 231J/K provides 20mA output current @ $80. (J), and $115. (K).

COMPLETE SPECIFICATIONS ARE GIVEN FOR THESE AMPLIFIERS ON PAGE 18.

FEATURES

Long Term Drift - 5μV/year
Voltage Drift - 0.1μV/°C
Low Noise - 1.5μV, p-p
Low Cost - $64. (1–9)

APPLICATIONS

Precision Integrators
Pico-Amp Current Measurements
Microvolt Voltage Measurements

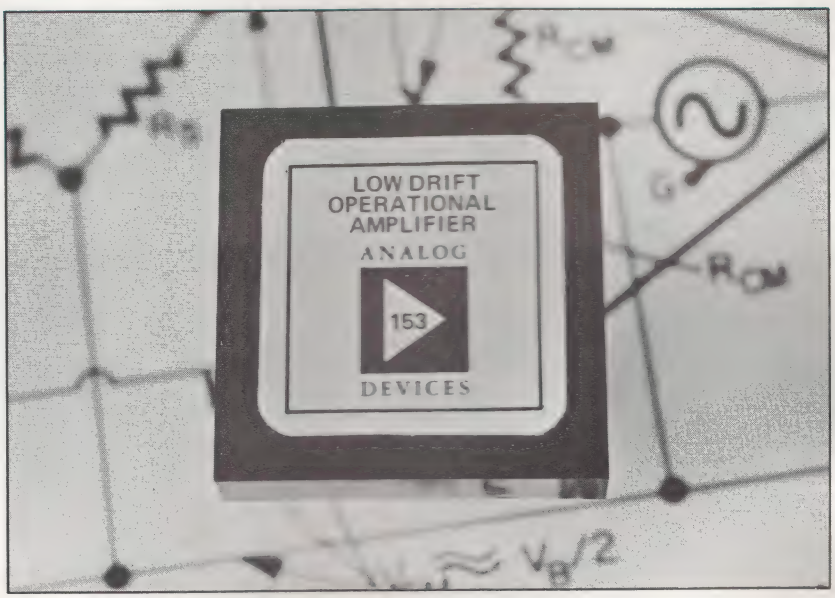
LOW VOLTAGE DRIFT DIFFERENTIALS

The single ended input of chopper stabilized amplifiers prohibits their use in many applications requiring low voltage drift. For this reason, the Models 180, 183, and 153 Chopperless Operational Amplifiers were specially designed to provide voltage drift comparable to that of chopper types and yet to offer the flexibility of differential inputs. In this way, low drift voltage followers with input impedance of 1000MΩ can be designed. Moreover, flicker noise of differential amplifiers is lower than that of chopper types — another advantage in many applications.

The Model 180 is the highest performance unit with voltage drift as low as 0.5μV/°C. The Model 183 is an economy version with reduced performance priced at $35. The Model 153 is identical to the 183 except with the additional feature of low quiescent current (70μA) for battery operation. Moreover, the Model 153 provides universal operation over a supply voltage range from ±2.7VDC to ±15VDC.

FEATURES

Voltage Drift - 0.5μV/°C
Stability - 5μV/month
Differential Inputs
Common Mode Rejection - 100dB
Input Impedance (CM) - 1000MΩ
Low Noise - 1μV, p-p
Battery Operation - 70μA drain (Model 153)
Wide Supply Voltage - ±2.7 to ±15VDC (Model 153)



SPECIFICATIONS	180J	180K	183J	183K
Open Loop Gain, min	300k	300k	200k	200k
Initial Offset Voltage, max	250μV	100μV	3mV	500μV
Offset Voltage Drift, max	1.5μV/°C	0.5μV/°C	5μV/°C	3μV/°C
Initial Bias Current, max	4nA	4nA	40nA	40nA
Bias Current Drift, max	0.1nA/°C	0.05nA/°C	0.5nA/°C	0.5nA/°C
Common Mode Rejection	100dB	100dB	100dB	100dB
Voltage Noise, dc to 1Hz	1μV, p-p	1μV, p-p	1μV, p-p	1μV, p-p
Long Term Stability	5μV/mo	5μV/mo	10μV/mo	10μV/mo
Price (1-9)	$75.	$95.	$35.	$45.

COMPLETE SPECIFICATIONS FOR THESE AMPLIFIERS ARE GIVEN ON PAGES 17 AND 18.

CHOPPER STABILIZED OP-AMPS

The 230 series sets new price standards for sophisticated chopper stabilized op amps. At $64. unit price, the Model 232 is less than one half the price of comparable units last year. Now OEM users will find it just as attractive to buy chopper stabilized op amps as they do the inexpensive differential types.

Performance of the 230 series has also been improved over previously available chopper amplifiers by using a new MOSFET chopper circuit. Long term drift tests indicate that initial offset voltage will stay within 5 microvolts indefinitely. Temperature drift of the "K" Model is less than an incredible 0.1μV/°C. Low frequency flicker noise, usually a limiting factor in chopper type designs, has been improved to 1.5μV peak to peak.

Three different models are offered: The Model 231 and 232, only 0.4" high for high density card file packaging, are the same except for output current of 20mA and 4mA respectively. The Model 230 is identical to the 232 except for a smaller volume package — 1.5" x 1.5" x 0.62".

Two versions of each model (J and K) allow you a selection of voltage and current drift performance.

	232J	232K
Open Loop Gain, min	10^7	10^7
Initial Offset Voltage, max	15μV	10μV
Offset Voltage Drift, max	.25μV/°C	0.1μV/°C
Long Term Stability	1μV/month	1μV/month
Voltage Noise, dc to 1Hz	1.5μV, p-p	1.5μV, p-p
Initial Bias Current, max	100pA	50pA
Bias Current Drift, max	1pA/°C	0.5pA/°C
Rated Output, min*	±10V@4mA	±10V@4mA
Price (1–9)	$64.	$99.

*Model 231J/K provides 20mA output current @ $80. (J), and $115. (K).

COMPLETE SPECIFICATIONS ARE GIVEN FOR THESE AMPLIFIERS ON PAGE 18.

FEATURES

Long Term Drift - 5μV/year
Voltage Drift - 0.1μV/°C
Low Noise - 1.5μV, p-p
Low Cost - $64. (1–9)

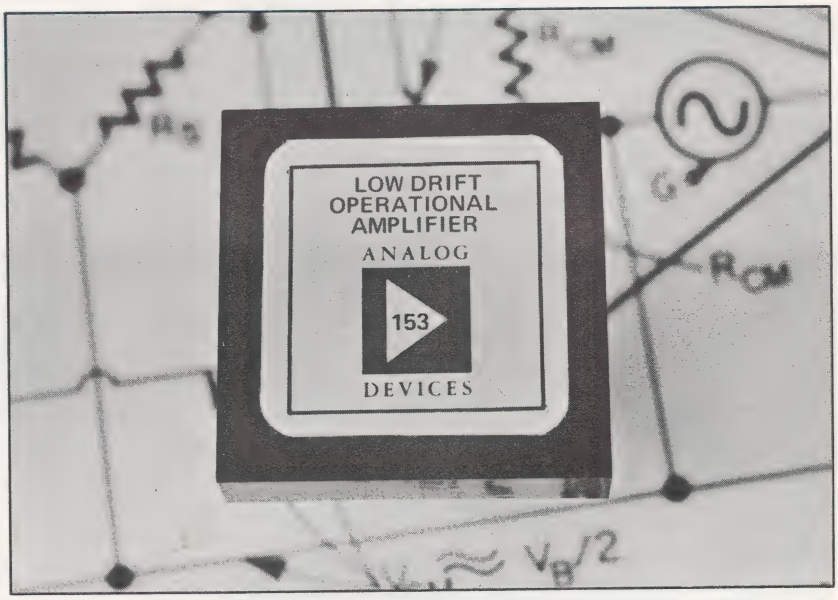
APPLICATIONS

Precision Integrators
Pico-Amp Current Measurements
Microvolt Voltage Measurements

LOW VOLTAGE DRIFT DIFFERENTIALS

The single ended input of chopper stabilized amplifiers prohibits their use in many applications requiring low voltage drift. For this reason, the Models 180, 183, and 153 Chopperless Operational Amplifiers were specially designed to provide voltage drift comparable to that of chopper types and yet to offer the flexibility of differential inputs. In this way, low drift voltage followers with input impedance of 1000MΩ can be designed. Moreover, flicker noise of differential amplifiers is lower than that of chopper types — another advantage in many applications.

The Model 180 is the highest performance unit with voltage drift as low as 0.5μV/°C. The Model 183 is an economy version with reduced performance priced at $35. The Model 153 is identical to the 183 except with the additional feature of low quiescent current (70μA) for battery operation. Moreover, the Model 153 provides universal operation over a supply voltage range from ±2.7VDC to ±15VDC.



FEATURES

Voltage Drift - 0.5μV/°C
Stability - 5μV/month
Differential Inputs
Common Mode Rejection - 100dB
Input Impedance (CM) - 1000MΩ
Low Noise - 1μV, p-p
Battery Operation - 70μA drain (Model 153)
Wide Supply Voltage - ±2.7 to ±15VDC (Model 153)

SPECIFICATIONS	180J	180K	183J	183K
Open Loop Gain, min	300k	300k	200k	200k
Initial Offset Voltage, max	250μV	100μV	3mV	500μV
Offset Voltage Drift, max	1.5μV/°C	0.5μV/°C	5μV/°C	3μV/°C
Initial Bias Current, max	4nA	4nA	40nA	40nA
Bias Current Drift, max	0.1nA/°C	0.05nA/°C	0.5nA/°C	0.5nA/°C
Common Mode Rejection	100dB	100dB	100dB	100dB
Voltage Noise, dc to 1Hz	1μV, p-p	1μV, p-p	1μV, p-p	1μV, p-p
Long Term Stability	5μV/mo	5μV/mo	10μV/mo	10μV/mo
Price (1-9)	$75.	$95.	$35.	$45.

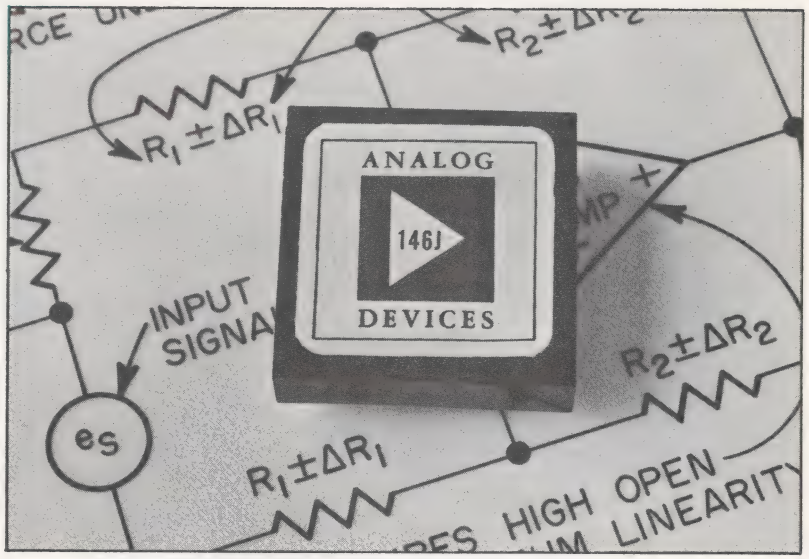
COMPLETE SPECIFICATIONS FOR THESE AMPLIFIERS ARE GIVEN ON PAGES 17 AND 18.

LOW BIAS CURRENT FET OP-AMPS

Analog Devices offers industry's broadest selection of FET input operational amplifiers. We have a model to meet the price and performance requirements of almost any application. A complete listing of models and specifications are included on Page 20.

The Model 144 and 146 are the latest additions to our FET line. The Model 144, at a price of only $18., is aimed at giving moderate performance at the lowest possible cost. However, the frequency response and noise characteristics of the 144 are superior to many FET amplifiers regardless of price.

The Model 146 is a significant achievement in obtaining low voltage drift (2μV/°C) in an FET amplifier at a modest cost, ($70.). Other superior features of this new amplifier include high CMRR, good frequency response and high output current.



FEATURES

MODEL 144
Low Cost - $18.
Low Noise - 3μV, rms (5Hz to 50kHz)
High Slew Rate - 6V/μsec
Bias Current - 100pA

MODEL 146
Voltage Drift - 2μV/°C
Low Bias Current - 20pA
High CMR - 10,000
High Slew Rate - 10V/μsec

SPECIFICATIONS	144A	144K	146J	146K
Open Loop Gain, min	50k	50k	100k	100k
Rated Output, min	10V@5mA	10V@5mA	10V@20mA	10V@20mA
Frequency Response	4MHz	4MHz	5MHz	5MHz
Slew Rate, min	6V/μsec	6V/μsec	10V/μsec	10V/μsec
Voltage Drift, max	100μV/°C	30μV/°C	7μV/°C	2μV/°C
Bias Current, max	100pA	100pA	30pA	20pA
Common Mode Rejection	60dB	60dB	80dB	80dB
Noise, dc to 1Hz	3μV, p-p	3μV, p-p	6μV, p-p	6μV, p-p
Price (1–9)	$18.	$28.	$57.	$70.

ELECTROMETERS

ULTRA LOW BIAS CURRENT

The Models 310 and 311 are varactor bridge input operational amplifiers which feature ultra low bias and noise currents. With typical bias current of 10^{-15}A, these varactor bridge amplifiers offer for the first time a realistic, solid state alternative to vacuum electrometer tubes which have traditionally been used for electrometer applications. Moreover, voltage drift of 10μV/°C achieved by the 310/311 is at least an order of magnitude improvement over the generally unsatisfactory stability of electrometer tubes or MOSFET devices. A price of only $50. in 100 lots is competitive with these less reliable and lower performance alternatives for electrometer applications.

The 310 is designed for inverting operation. It is particularly useful where infinitesimal currents must be converted to voltage levels for measurement or control. This kind of application is typified by photomultiplier tubes and gas chromatograph flame detectors. The 10^{-15}A bias current of the 310 means that extremely low current levels may be observed with high accuracy.

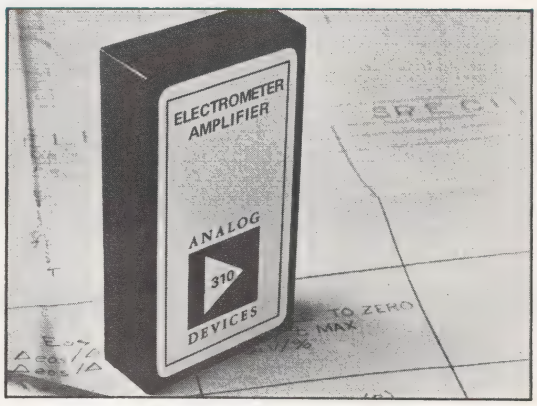
The 311 is essentially identical to the 310 but is optimized for non-inverting circuits. This model is the best choice where voltages must be measured from very high impedance sources such as are found in pH cells and other transducers of chemical and biological phenomena.

FEATURES

Bias Current .01pA, max
Current Noise, .001pA, p-p
Bias Current Drift doubles every 7°C
Input Impedance 10^{14} ohms
Voltage Drift 10μV/°C
Price (100 lot) - $50.

APPLICATIONS

Electrometer Amplifier
Picoamp Measurements
Long Term Integration
PH Measurements
Flame Detector Amplifier
Photomultiplier Tube Amplifier
Nine Decade Log Amplifier



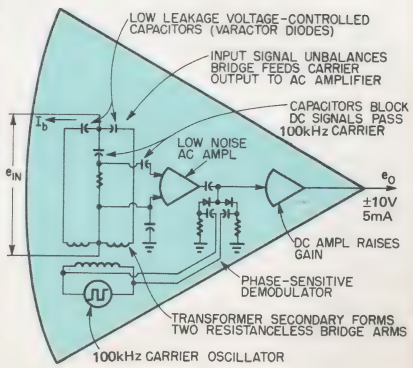
HOW THE 310/311 WORK

Amplifier input, e_{in}, varies varactor capacitances, unbalances bridge, and develops pump voltage output proportional to bridge unbalance.

After low noise AC amplification, the output pump voltage is phase-sensitively demodulated to restore correct polarity, then further boosted by the DC amplifier.

Final output is a replica of the original signal, amplified by the open loop gain.

Matched low leakage varactors inherently eliminate 1/f noise, give excellent offset and drift specs, and provide $3x10^{11}$ ohms differential input impedance. Transformer coupling is responsible for the amplifier's advanced common mode characteristics.


LOW LEAKAGE VOLTAGE-CONTROLLED CAPACITORS (VARACTOR DIODES)
INPUT SIGNAL UNBALANCES BRIDGE FEEDS CARRIER OUTPUT TO AC AMPLIFIER
CAPACITORS BLOCK DC SIGNALS PASS 100kHz CARRIER
LOW NOISE AC AMPL
DC AMPL RAISES GAIN
PHASE-SENSITIVE DEMODULATOR
TRANSFORMER SECONDARY FORMS TWO RESISTANCELESS BRIDGE ARMS
100kHz CARRIER OSCILLATOR
±10V 5mA

FET COMPARATOR MODULE

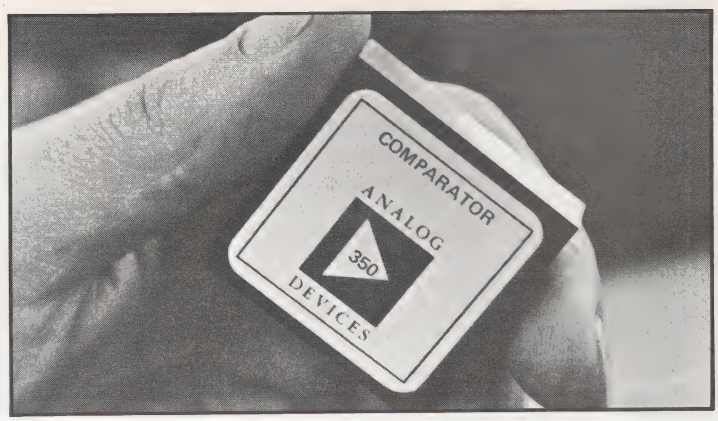
MODEL 350

FEATURES

High Gain
High Input Impedance at Comparison Point
Low Drift
DTL, TTL, or RTL Levels
High Current Capability
10 Volt Differential and Common Mode Range

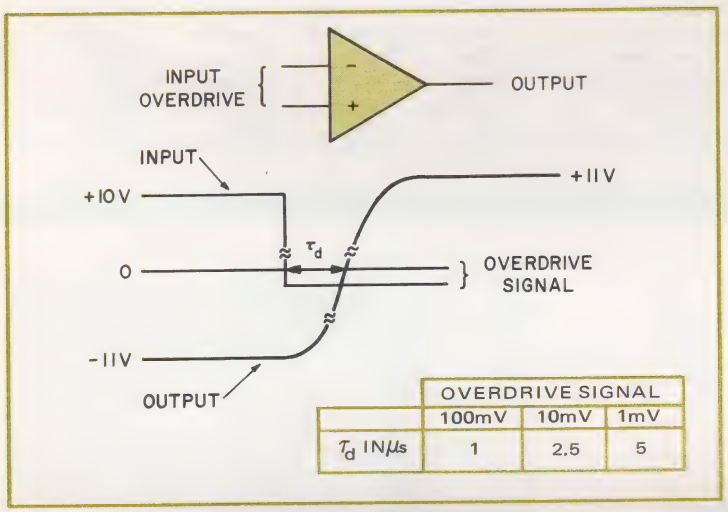
APPLICATIONS

A/D Converter
Zero Crossing Detector
Square Wave Generator
Pulse Generator
Voltage To Frequency Conversion
Pulse Width Modulation



The new Analog Devices' Model 350 is a miniature encapsulated comparator module with high impedance FET inputs, excellent "trip point" stability, fast response characteristics, and logic compatible outputs. The 350 is designed as an open loop operational amplifier. It is different from general purpose op-amps principally in that it is a bistable, limit-to-limit device. Switching characteristics have been optimized, as well as input stability parameters. The 350 is intended for applications requiring comparison rates from DC to approximately 100kHz. Performance is well beyond that of IC types.

Operation of the comparator is illustrated below. The output is clamped at either the positive or negative voltage "state," dependent upon the relative polarity of the input signal. A step input (change of polarity) will result in a transition to the opposite state. While an ideal comparator will respond instantaneously, a practical device will exhibit a slight delay time. Delay time (τ_d) is specified at the midpoint of the voltage transition, and is a function of the input signal overdrive. The table shows typical 350 performance.



	OVERDRIVE SIGNAL		
	100mV	10mV	1mV
τ_d INμs	1	2.5	5

SPECIFICATIONS

MODEL	A/B/C
SENSITIVITY @1.5k load, min	20V/400μV
RATED OUTPUT, Voltage min With Limit pin grounded	$\pm$10V@$\pm$7mA +5V$\pm$0.6V@15mA 0V$\pm$0.1V@20mA
INPUT OFFSET VOLTAGE	$\pm$2mV[1]
Avg. vs. temp (−25 to +85°C) max	$\pm$75/40/25μV/°C[2]
INPUT BIAS CURRENT, 25°C, max	50/30/30pA
vs. temp (−25 to +85°C) max	5/3/3nA
INPUT DIFFERENCE CURRENT, 25°C	10pA
INPUT IMPEDANCE Differential and common mode	$10^{11}\Omega$||3.5pF
SWITCHING TIME	
$\pm$1V input, 20V output swing	0.5μsec
$\pm$1V input, 5V output swing	0.1μsec
OUTPUT DELAY, 1mV overdrive, max	10μsec[3]
INPUT VOLTAGE RANGE	
Common mode rejection @ $\pm$10V	1000
Max. safe differential voltage	$\pm$30V
POWER SUPPLY	$\pm$15V@3.5mA
TEMP. RANGE	−25 to +85°C
CASE STYLE	F-1
PRICE, 1-9	$40/$50/$70
10-24	$38/$48/$67

[1]With a 499 ohm trim; adjustable to 0 with 1k pot.
[2]Zeroed at 25°C.
[3]See Figure on left.

FAST SETTLING OP-AMPS

MODELS 148, 149, 120, 220

Models 148, 149, 120, and 220 are operational amplifiers designed for use in high speed/high precision applications. Specifically, where wide bandwidth, high slewing rate, and fast settling time to high accuracy is important, these amplifiers are particularly useful.

A/D and D/A converters are representative of types of circuits requiring fast settling time. This is true because, among other considerations, the minimum conversion time of any A/D or D/A converter is limited by the amplifier settling time. Settling time is the time required for the op amp to settle to its final value within the required limits of accuracy. Stated another way, if 0.01% accuracy of conversion is required, a conversion cannot be made in a shorter period than the time required for the amplifier to settle to within 0.01% of its final value. This is shown graphically at the right.

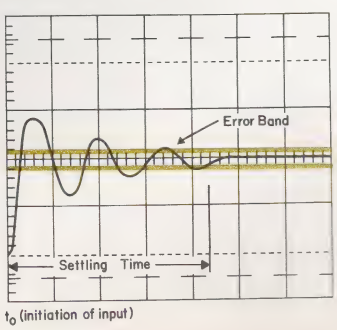
These amplifiers are designed to settle to 0.01% in $<$1μsec (1.5μsec, Model 149) and are ideal for use in high accuracy/high speed applications. Models 148 and 149 are useful as both inverters and non-inverters; Model 220 is chopper stabilized. Complete specifications on all types appear on page 19.

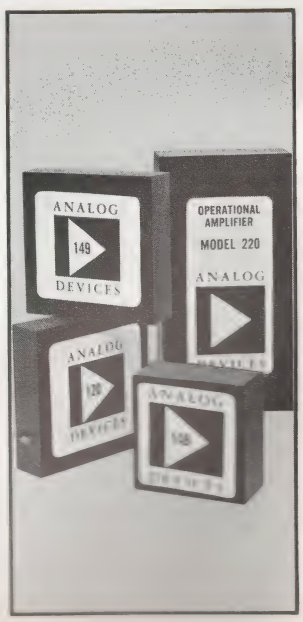
FEATURES

Fast Settling Time .01% in 1μsec
Fast Slew Rate 250V/μsec
Low Drift 0.2μV/°C (220B)

APPLICATIONS

A/D Converter
Wideband Amplifier





POWER SUPPLIES MODELS 901, 902, 903

The Models 901 and 902 dual power supplies were designed specifically to power operational amplifiers operating from ±15VDC. The units connect directly to 115VAC line power and produce two fixed 15 volt outputs. Model 901 supplies ±40mA from each output, and the 902 provides ±100mA each. Model 903 is a single output 5 volt power supply and supplies 500mA. All three supplies are epoxy cast into modules that can be soldered directly onto printed circuit boards or that can be plugged into an optional mating socket. Hold down nuts are provided to mechanically secure any module.

The units are designed with regulation, ripple, and noise specifications which are consistent with the requirements of most modern op-amp and logic systems. They are small, inexpensive, and ideally suited to OEM application.

The Model 950 is a bench mount manifold which will accept any of these power supplies. The supplies simply plug in and may be removed or replaced. Once installed, they may be safely and conveniently used in the laboratory. A line fuse is incorporated as well as universal output terminals, a toggle switch and four soft rubber feet. Unit cost is just $16.

FEATURES

Dual Output ±15VDC @ 40mA or 100mA for Op-Amps

5V @ 500mA for Logic Card

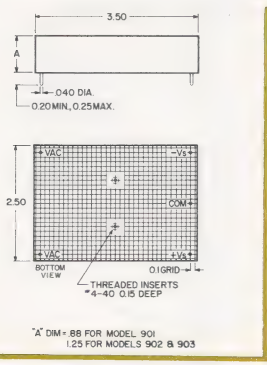
Operate from 115VAC 50–400 Hz

Bench Mount Manifold Accessory

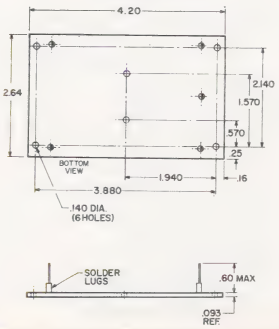
Low Cost

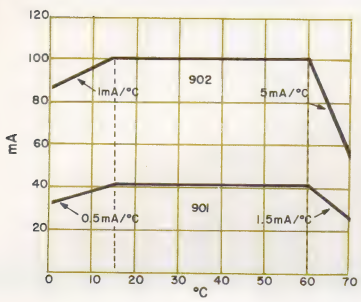
- $16. (950)
- $39. (901 quantity 10)
- $56. (902 quantity 10)
- $47. (903 quantity 10)

OUTLINE DIMENSIONS



MATING SOCKET AC1013
$3.50 (1-9)





Both Models 901 and 902 operate over a 0 to 71°C temperature range, however the output current is derated outside the range of +15°C to +60°C as shown on the left. The outputs of either supply will sustain an indefinite short circuit of either output (plus or minus) to common at any temperature from 0 to 71°C. Under these conditions output current is limited to approximately 20mA for the 901 and 25mA for the 902.

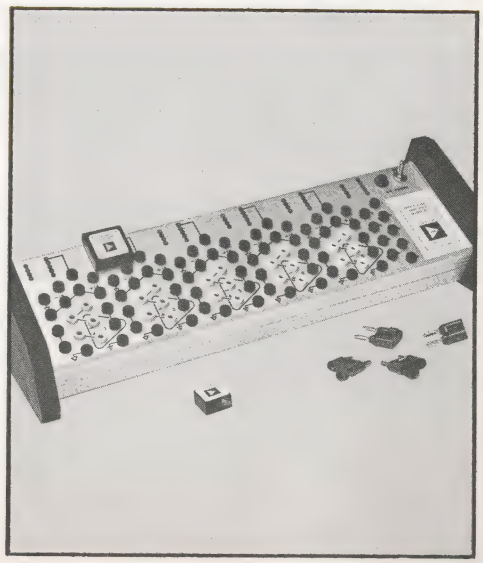
	MODEL 901	MODEL 902	MODEL 903
INPUT VOLTAGE	105 to 125VAC[1]	*	*
	50 to 400Hz	*	*
	7VA max	17VA max	17VA max
OUTPUT VOLTAGE	±15VDC	±15VDC	5VDC
OUTPUT CURRENT	40mA	100mA	500mA
TRACKING (–V, +V)	±1%	*	NA
TEMP. COEFF. max	0.03%/°C	0.015%/°C	0.02%/°C
WARM UP DRIFT	±0.25% (37mV)	±0.3% (45mV)	±0.3% (15mV)
REGULATION			
Line (105–125)	0.1% max	0.05% max	0.15% max
Load (0–100%)	0.2% max	0.1% max	0.3% max
RIPPLE rms	2mV	0.5mV	1mV
Peak to Peak, max	10mV	2mV	5mV
INPUT ISOLATION	50 Megohms	*	*
OUTPUT Z @ 10kHz	2 ohms	2 ohms	.025 ohms
SHORT CIRCUIT PROTECTION	+ or – to common	*	*
OPERATING TEMP.	0 to 71°C	*	*
Above 60°C	Derate 1.5mA/°C	Derate 5mA/°C	See note 2
Below 15°C	Derate 0.5mA/°C	Derate 1mA/°C	See note 2
STORAGE TEMP.	–25 to +85°C	*	*
WEIGHT	9.5 oz.	16 oz.	16 oz.
PRICE (1-9)	$49.	$59.	$49.
(10-24)	$39.	$56.	$47.

[1]Input voltage of 205 to 240VAC available. Specify Model E.
[2]Derate 12mA/°C above 50°C and 10mA/°C below 15°C.
Specifications subject to change without notice.

OPERATIONAL MANIFOLD MODEL 194

This new operational amplifier manifold is ideal for experimenting, breadboarding, and/or teaching with op-amps. Completely self-contained, the Model 194 includes a dual ±15V 40mA power supply, on-off switch, fuse, line cord, and mounting hardware. It accepts up to 5 amplifiers of the popular 7 pin "Q" case pin configuration. Adapters are available for integrated circuit amplifiers and our microcircuit hybrid types. Provisions are made for a balance resistor or potentiometer for each amplifier.

The panel design is carefully organized to provide a maximum of interconnection flexibility. The inputs and output of each amplifier are arranged schematically on the panel. All adjacent connection points are equilateral triangles on 3/4 inch spacing, and input and feedback components are mounted on dual banana type fixtures. These are simply plugged into the "schematic" representation as desired, and almost as simply as drawing a circuit, the performance of your design may be verified or demonstrated. The device is invaluable in the classroom or on the design bench. The 194 is available as a 19 inch rack mounted panel or with attractive walnut end-pieces for desk or bench use. Price of either model is $250. each (1-9 manifolds), substantially less for higher quantities.



ANALOG MULTIPLIERS

FEATURES

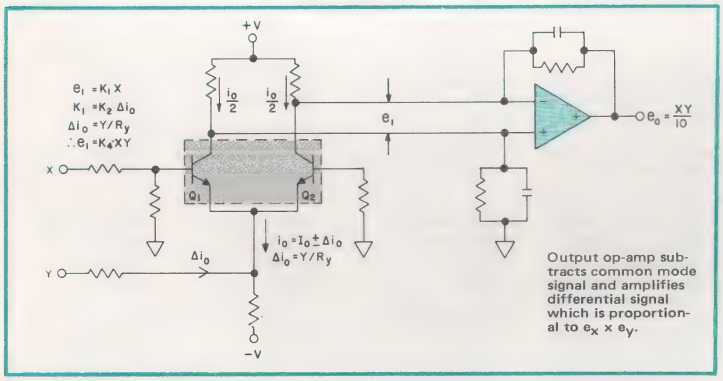
Four Quadrant Operation
Small Size - 1.5 x 1.5 x .62 in.
Fast Response - 5MHz
Low Cost - $75. (100 lot)

APPLICATIONS

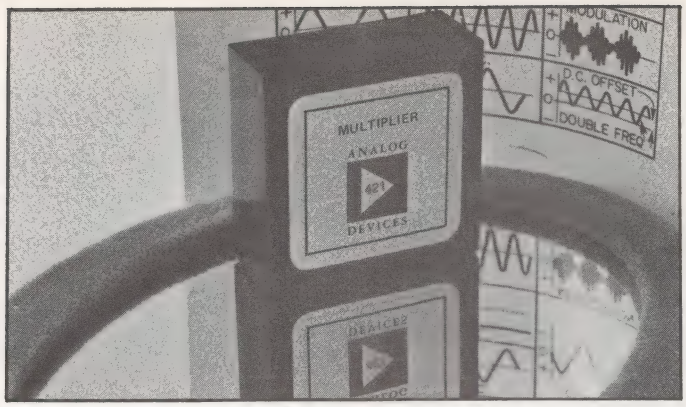
Precision Gain Control
Power Measurements
Trigonometric Computation
Modulation and Demodulation

The Model 422J/K is an all solid state, four quadrant low cost, fast response multiplier module. Operation is based on using one of the input signals to vary the transconductance (and therefore the gain) of an input transistor stage which in turn amplifies the other input signal. As compared to other multiplier circuits, this technique is quite simple and therefore offers advantages of small size and low cost. Additionally, this technique inherently achieves fast response and therefore good accuracy at high frequencies.

Performance achieved by the Model 422J/K clearly sets new standards for multipliers priced below $100. Foremost, its 5MHz bandwidth opens entirely new application possibilities for low cost multipliers. Accuracy has also been improved by a new circuit technique which substantially reduces drift and noise errors. Fixed internal "trims" eliminate the need for external pots except as options to improve performance.



A simplified circuit in the figure above illustrates the principles of operation. A differential amplifier stage formed by transistor pair Q_1 and Q_2 amplifies signals at input X which are applied to the base of Q_1. The gain factor, K_1, is proportional to the transconductance of Q_1. Transconductance (and therefore gain) of the input stage is thus linearly proportional to collector current, over a limited range of operation. By using the Y input signal to vary emitter current, the gain of the input stage can be controlled, achieving the desired multiplication function. An op amp, connected differentially, subtracts the common mode signal from the input pair and amplifies the differential signal. This signal is then proportional to the product of inputs X and Y.



SPECIFICATIONS

TRANSFER FUNCTION	
Gain, max.	XY/10±1%
vs. temp	0.03%/°C
NON-LINEARITY (Best straight line)	
X input, max.	±60mV or ±0.6%
Y input, max.	±30mV or ±0.3%
OUTPUT OFFSET (X=Y=0)	
vs. temp, max. Model 422J	4mV/°C or 0.04%/°C
Model 422K	2mV/°C or 0.02%/°C
vs. supply	3mV/% or 0.03%/%
FEEDTHROUGH	
X=0, Y=0 to 20V p-p	0.1% of Y
Y=0, X=0 to 20V p-p	0.05% of X
OUTPUT CHARACTERISTICS	
Voltage, min.	±10V
Current, min.	±10mA
Resistance	1 ohm
Noise, 5Hz to 10kHz	300μV, rms
5Hz to 4MHz	1mV, rms
INPUT RESISTANCE (X and Y)	10k ohms ±10%
FREQUENCY RESPONSE	
Small signal (amplitude)	−3dB@5MHz
Full power response (distortion)	500kHz
Vector error (phase)	1% (0.57°)@30kHz
Slewing rate	30V/μsec
Overload recovery	1μsec
POWER SUPPLY	±15V@21mA
TEMPERATURE RANGE	
Operating, rated specifications	10 to 60°C
Operating, derated specifications	−25 to +85°C

PRICE	422J	422K
1–9	$95.	$120.
10–24	$85.	$105.

Mating socket — AC 1012 (1–9) $4.00.
Specifications subject to change without notice.

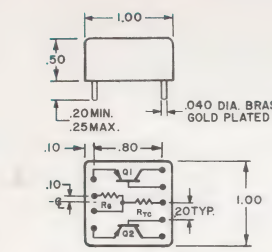
LOGARITHMIC MODULES

MODEL 751P/N

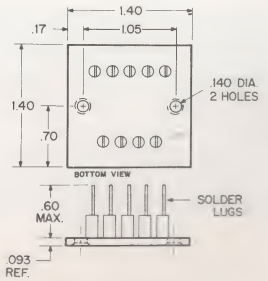
Model 751P/N Logarithmic Modules contain the nonlinear components needed to instrument a wide range of exponential, logarithmic and ratio measuring circuits. The circuitry includes a pair of silicon transistors — NPN types in the Model 751N and PNP types in the Model 751P — and a temperature compensating voltage divider.

The transistors are chosen for their conformity to the ideal logarithmic current-to-voltage relationship; their characteristics are closely matched and they are thermally coupled to minimize temperature differences between their junctions. The voltage divider, used in the feedback network of an operational amplifier, is designed to boost the voltage difference between the two transistors to one volt per decade of current ratio through them, while simultaneously compensating for the temperature dependence of the matched transistor pair. Each module is adjusted and calibrated to assure compliance to the specifications.

The Model 751P/N is normally used in conjunction with one or more operational amplifiers and thus the circuitry of the module is brought out on separate pins to allow maximum versatility of interconnection. The unit is molded into an epoxy filled module which can be soldered directly onto a printed circuit board or plugged into an optional mating socket. Devices manufactured to custom designs are also available.



AC 1016
Price (1–9) $3.00



FEATURES

Wide Dynamic Range 10pA to 1mA
Calibrated 1V/Decade Output
Temperature Compensated to 0.05%/°C
Low Cost - $15. (100 quantity)
$38. (1-9)

INSTRUMENTATION AMPLIFIERS

MODELS 601 AND 602

FEATURES • Small Size • Low Cost
Fixed or Variable Gain • High CMRR

Models 601 and 602 are modular encapsulated data instrumentation amplifiers. They are designed for use in data acquisition applications or other instrumentation applications where high input impedance, differential inputs, high common mode rejection and gain accuracy are important. They differ from operational amplifiers in that they include internal feedback networks and are themselves closed-loop/stable-gain devices.

The Model 602 is available with fixed gain of either 10 or 100. The higher gain model may be further selected for less than ±2μV/°C temperature coefficient (RTI).

Model 601 is for more exacting applications, or where variable gain is required. A single external resistor will vary the gain from 20 - 2000. Full power bandwidth is greater than that of the 602 and the package size is somewhat larger.

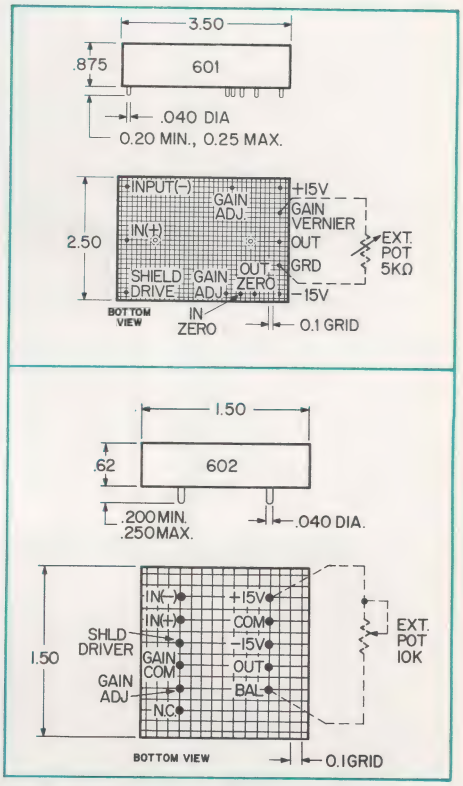
The small size of these instruments (1.5 x 1.5 x .62 in. for the 602 and 3.5 x 2.5 x .875 in. for the 601) means that the amplifier can often be located very near to the transducer or other signal source. This not only minimizes noise pick-up, but also reduces the complexity of long input lines, racks, connectors and other mechanical hardware required for the more expensive rack mounted types.

SPECIFICATIONS

	601	602-J/K-100	602-J-10
GAIN CHARACTERISTICS			
Range	20-2000 (selected by external resistor)	100[1]	10[1]
Accuracy	adj. to ±.01% by external gain pot	Internally trimmed to 0.05% max	Internally trimmed to ±0.05% max
Stability	±.02%/month	±.02%/month	±.02%/month
Temperature Coefficient	±.003%/°C	±.001%/°C	±.001%/°C
Nonlinearity @ DC	±.02% (best straight line)	±.01% (best straight line)	±.01% (best straight line)
OFFSET CHARACTERISTICS			
Offset Voltage			
Initial Offset, 25°C, max	±150μV RTI (adj. to 0)[2]	±200μV(A)±100μV(B) RTI (adj. to 0)[2]	±300μV RTI (adj. to 0)[2]
Temperature Drift, max	2μV/°C RTI plus 2mV/°C RTO	±10μV/°C(A); ±2μV/°C(B)	±10μV/°C RTI
Drift Stability - per day	±10mV RTO	±10μV RTI	±10μV RTI
Supply, Voltage Influence	±20μV/% RTI (3k source)	±10μV/% RTI (1k source)	±10μV/% RTI (1k source)
Bias Current (each input)			
Initial, 25°C, max	±10nA	±50nA	±50nA
Temperature Drift, max[3]	±300pA/°C	±1nA/°C	±1nA/°C
INPUT CHARACTERISTICS			
Full Scale Voltage Range	±(5-100)mV	±100mV	±1000mV
Differential Impedance	10MΩ paralleled with 1000pF	1000MΩ paralleled with 50pF	1000MΩ paralleled with 50pF
Overvoltage, max	±10V (with no damage)	±10V differential, ±10V each input to ground	±10V differential, ±10V each input to ground
CMR, min @ ±10V	120dB, DC-60Hz (1k source unbalance)	100dB, DC-60Hz (1k source unbalance) 86dB, DC-500Hz (1k source unbalance)	80dB, DC-60Hz (1k source unbalance) 75dB, DC-500Hz (1k source unbalance)
OUTPUT CHARACTERISTICS			
Output Rating	±10V @ 20mA (DC to 20kHz)	±10V @ 4mA (DC to 10kHz) min	±10V @ 4mA (DC to 8 kHz) min
Output Resistance	0.5 ohms	0.5 ohms	0.5 ohms
Short Circuit Limit	±100mA	±70mA	±70mA
RESPONSE CHARACTERISTICS			
Frequency Response	1% from DC-1kHz ±3dB from DC-30kHz	−1% from DC-1kHz (gain-of-100) −3dB from DC-75kHz (gain-of-100)	−1% from DC-1kHz (gain-of-10) −3dB from DC-75kHz (gain-of-10)
Settling Time to 0.1%	100μsec for full scale step	50μsec	50μsec
Overload Recovery	1msec	200μsec	200μsec
POWER REQUIREMENTS			
Supply Voltage	±(15 to 16)VDC	±(15 to 16)VDC	±(15 to 16)VDC
Supply Current, max	60mA Quiescent	14mA Quiescent	14mA Quiescent
PRICE		Model A Model B	
1–9	$225.	$75. $100.	$75.
10–24	$215.	$70. $90.	$70.

1. May be varied to 1000 by ext. resistor with degraded specs 2. With external pot. 3. Avg. from −25°C to +75°C(601); avg. from 0°C to 70°C(602)

Notice: Specifications subject to change without notice.

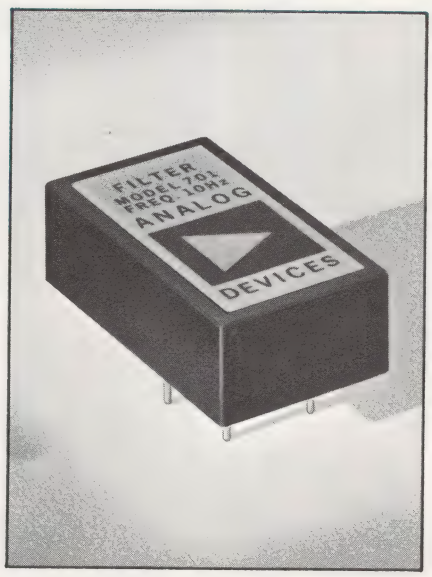


ACTIVE FILTERS

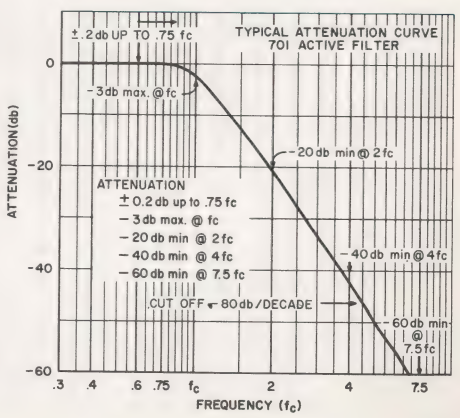
MODEL 701

Analog Devices has designed and built a large number of active filter modules. Small package size, high input impedance and low drift rates make these devices extremely attractive in many filtering applications. The devices are typified by the Model 701 — a low pass model with ±0.2dB flatness and a sharp cutoff slope of 80dB/decade. Cost for standard frequency versions of the 701 is as low as $75.

Because of the large number of variables in a given design (cutoff frequencies, attenuation slopes, pass bands, etc.), most of these are furnished as custom tailored modifications of our existing designs. Please contact our Applications Engineering Department for detailed information on available devices.



FREQUENCY RESPONSE CURVE



SPECIFICATIONS

SELECTION BY CLASSIFICATION — In preparing these amplifier specification charts, we have classified our products into six groups, according to general application requirements. In doing this, we have established what we feel are logical categories to serve as a point of departure in the selection of the optimum amplifier for a given set of application requirements. Some amplifiers appear in more than one chart.

Low Cost/Moderate Performance — This group includes our lowest cost devices. These amplifiers are intended for general purpose applications where moderate voltage drift, impedance levels and bandwidth is adequate. Bias current drift of these amplifiers is in the range from .15 to .7nA/°C while voltage drift is in the range from 1.5 to 40μV/°C. Therefore, these amplifiers give best performance where external circuit impedances are below 100k ohms. Additionally, amplifiers in this group have modest bandwidth, below 1.5MHz unity gain and 100kHz full power response. In general, this chart should be consulted before any other, as an acceptable amplifier found here will be the least expensive choice for any given set of requirements.

Low Voltage Drift — These amplifiers feature the lowest voltage drift specifications available, in the range from 0.1 to 3μV/°C. Included are transistor, FET and chopper stabilized types. Applications include critical low level signal instrumentation, high accuracy integrators, low level comparators and other uses where minimum offset voltage error is of prime importance.

Wideband, Fast Response — This group includes all amplifiers which emphasize wide bandwidth and fast response in their design. Unity gain bandwidth for these amplifiers is 10MHz or greater and other key specifications such as full power response, slewing rate and settling time are outstanding.

Low Bias Current/FET Input — FET input designs are used in these amplifiers to obtain lower bias current and higher input impedance than is possible with bipolar transistor types. These amplifiers give better accuracy than those in the low cost category where impedance levels are above 100k ohms and are almost essential for impedance levels above 1 megohm. The lower bias current provided by these amplifiers gives higher accuracy in such applications as integrators, sample and hold circuits and current to voltage amplifiers.

Ultra Low Bias Current/Varactor Bridge — The amplifiers in this category are designed for ultra low bias currents and high input impedance. Input bias current on the order of 10 femtoamperes (10^{-15}A) and input impedance as high as 10^{14} ohms are found here. These op amps are solid state replacements for vacuum electrometer tube amplifiers and are an attractive alternative to MOSFET devices. Applications include ultra high sensitivity current-to-voltage transducers and where voltages must be measured from extremely high impedance sources. These devices are most useful in chemical, biological, and other scientific instrumentation.

High Output Capability — Amplifiers in this category are unique with respect to their output voltage and/or current capability. In general, amplifiers with output voltage/swing of ±20 volts or ±100 volts as well as those with current capability to 100mA are featured. The B100 output current booster module is also included.

HOW TO USE THE SPECIFICATION CHARTS — Most of our basic op-amp models are offered with "selected" parameters. Specifically, voltage drift, input bias current, and bias current drift are guaranteed to fall within certain maximum limits. This selection is indicated by a letter suffix added to the model number, to indicate the guaranteed coefficients. Another variable in this selection process is the temperature range over which the amplifier is tested. A suffix of J, K, or L, for example, indicates testing over the "normal usage" environment range of +10°C to +60°C. A suffix of A, B, or C indicates testing over the extended temperature range of −25°C to +85°C. It should be emphasized that these are the temperature ranges over which the amplifier has been tested (and therefore specified) but almost all models will operate (with derated performance) substantially beyond these limits. The charts are coded to indicate the available models as shown below:

(NEW) DENOTES NEW PRODUCTS

MODEL & COLOR CODE	MODEL 114			MODEL 115			MODEL 118 (NEW)		
								K	
	A	B	C	A	B	C	A		
All specifications typical @ 25°C and nominal supply voltage unless otherwise specified.	LOW BIAS CURRENT 20mA OUTPUT			LOW COST LOW BIAS CURRENT			LOWEST COST GENERAL APPLICATION		
OPEN LOOP GAIN									
dc, rated load, min	5×10^5			10^5			2.5×10^5		
RATED OUTPUT, min	±10V @ 20mA			±10V @ 2.5mA			±10V @ 5mA		
INPUT OFFSET VOLTAGE @ 25°C, max	Adj to 0			Adj to 0			Adj to 0		
Average vs. temp 10 to 60°C, max, μV/°C♦								±5	
−25 to 85°C, max, μV/°C♦	±15	±10	±5	±20	±10	±5	±20		
vs. supply	±20μV/%			±20μV/%			±10μV/%		
vs. time	±100μV/mo			±250μV/mo			±200μV/mo		
INPUT BIAS CURRENT @ 25°C, max	±2nA			(0,+) 12nA			(0,+) 35nA		
Average vs. temp 10 to 60°C, max, nA/°C								±.5	
−25 to 85°C, max, nA/°C	±.15nA/°C			±.2nA/°C			±.6		
INPUT DIFFERENCE CURRENT @ 25°C	±2nA			±2nA			±3nA		
Average vs. temp 10 to 60°C, nA/°C								±.05	
−25 to 85°C, nA/°C	±.05nA/°C			±.05nA/°C			±.1		
PRICE									
1-9	$45.	$50.	$55.	$18.	$23.	$28.	$11.	$21.	
10-24	$43.	$48.	$53.	$17.	$22.	$27.	$10.50	$19	

KEY SPECIFICATIONS APPEAR IN COLOR

LOW COST / MODERATE PERFORMANCE OPERATIONAL AMPLIFIERS

MODEL & COLOR CODE	MODEL 114			MODEL 115			MODEL 118 (NEW)			MODEL 119 (NEW)			MODEL 150	MODEL 153 (NEW)		MODEL 183			MODEL 801 (NEW)		
								K			K			J	K		K	L			S
	A	B	C	A	B	C	A			A						◇	◇	◇	A	B	
All specifications typical @ 25°C and nominal supply voltage unless otherwise specified.	LOW BIAS CURRENT 20mA OUTPUT			LOW COST LOW BIAS CURRENT			LOWEST COST GENERAL APPLICATION			LOWEST COST 20mA OUTPUT			BATTERY OPERATED LOW VOLTAGE	BATTERY OPERATED LOW CURRENT DRAIN		LOW VOLTAGE DRIFT			LOW BIAS CURRENT I.C. MICROCIRCUIT		
OPEN LOOP GAIN																					
dc, rated load, min	5 x 10^5			10^5			2.5 x 10^5			5 x 10^5			10^4	5 x 10^4☆		2 x 10^5			1.5 x 10^4		
RATED OUTPUT, min	±10V @ 20mA			±10V @ 2.5mA			±10V @ 5mA			±10V @ 20mA			±1.5V @ 2.5mA	±1V@ 1mA☆		±10V @5mA			±10V @ 5mA		
FREQUENCY RESPONSE																					
Unity gain, small signal	500kHz			500kHz			1.5MHz			1.5MHz			1.5MHz	150kHz		500kHz			500kHz▲		
Full power response, min	2kHz			2kHz			100kHz■			100kHz■			50kHz	5kHz (peak)☆		5kHz			3kHz▲		
Slew rate, min	.12V/μsec			.12V/μsec			6V/μsec■			6V/μsec■			1.2V/μsec	.02V/μsec		.3V/μsec			.25V/μsec▲		
Overload recovery	5msec			30msec			.5msec			.5msec			1msec	2msec		2msec			50μsec▲⊕		
INPUT OFFSET VOLTAGE @ 25°C, max	Adj to 0			Adj to 0			Adj to 0			Adj to 0			Adj to 0	±1mV	±250μV		±.5mV	±.5mV	±5mV		
Average vs. temp 10 to 60°C, max, μV/°C◆								±5			±5			±5	±2						±20□
–25 to 85°C, max, μV/°C◆	±15	±10	±5	±20	±10	±5	±20			±20			±20			◇	◇	◇	±40	±10	
vs. supply	±20μV/%			±20μV/%			±10μV/%			±10μV/%			±20μV/%	±1μV/%		±10μV/%			±30μV/%		
vs. time	±100μV/mo			±250μV/mo			±200μV/mo			±200μV/mo			±250μV/mo	±10μV/mo		±10μV/mo			±100μV/mo		
INPUT BIAS CURRENT @ 25°C, max	±2nA			(0,+) 12nA			(0,+) 35nA			(0,+) 35nA			(0,+) 50nA	±3nA		(0,+) 40nA			(0,+) 4nA		
Average vs. temp 10 to 60°C, max, nA/°C								±.5			±.5			±.1nA/°C		±.5nA/°C			±.15nA/°C□		
–25 to 85°C, max, nA/°C	±.15nA/°C			±.2nA/°C			±.6			±.6			±.7nA/°C			◇			±.15nA/°C		
INPUT DIFFERENCE CURRENT @ 25°C	±2nA			±2nA			±3nA			±3nA			±5nA	±3nA		±4nA			±2nA★		
Average vs. temp 10 to 60°C, nA/°C								±.05			±.05			±.05nA/°C		±.05nA/°C					±.03□
–25 to 85°C, nA/°C	±.05nA/°C			±.05nA/°C			±.1			±.1			±.2nA/°C			◇			±.1	±.02	
INPUT IMPEDANCE																					
Differential	4MΩ			4MΩ			1MΩ			1MΩ			1MΩ	1MΩ		2MΩ			25MΩ		
Common mode	500MΩ			1000MΩ			1000MΩ			1000MΩ			100MΩ	200MΩ		1000MΩ			500MΩ		
INPUT NOISE																					
Voltage .01Hz to 1Hz p-p	2μV			2μV			1μV			1μV			2μV	1μV		1μV			30μV		
5Hz to 50kHz rms	4μV			4μV			3μV			3μV			4μV	2μV●		12μV			26μV		
Current .01Hz to 1Hz p-p	30pA			10pA			20pA			20pA			150pA	10pA		50pA			4pA		
INPUT VOLTAGE RANGE																					
Absolute max. differential	±15V			±15V			±15V			±15V			±15V	±15V		±15V			±10V		
Common mode voltage	>10V			>10V			>10V			>10V			>1V	>1V☆		>10V			>10V		
Common mode rejection	10,000 @ ±10V			10,000 @ ±10V			20,000 @ ±10V			20,000 @ ±10V			10,000 @ ±1V	50,000 @ ±1V		100,000 @±10V			15,000 @ ±8V		
POWER SUPPLY	±15V @ ±4mA			±15V @ ±4mA			±15V @ ±4mA			±15V @ ±2mA			±3.3V @ ±.8mA	±2.7V @ ±70μA☆		±15V @ ±9mA			±15V @ ±3mA		
STORAGE TEMPERATURE RANGE	–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C	–55°C to +125°C		–55°C to +125°C			–65°C to +150°C		
CASE STYLE (See pp. 26-29)	L-4			M-1			M-1			F-1			Q-1	F-1		F-1			Low Profile. TO –99		
PRICE																					
1-9	$45.	$50.	$55.	$18.	$23.	$28.	$11.	$21.		$24.	$34.		$22.	$40.	$50.	$35.	$45.	$65.	$14.	$19.	$23.
10-24	$43.	$48.	$52.	$17.	$22.	$27.	$10.50	$19		$20.	$29.		$21.	$38.	$48.	$33.	$43.	$62.	$14.	$19.	$23.

NOTES: ◆See Page 7 for explanation of measurement techniques.

■20kHz and 1.2V/μsec for non-inverting operation.

☆See Page 10 for operation from other voltages from ±2.7V to ±15V.

●10Hz to 10kHz.

◇Models A/B/C available with same specifications over the temperature range of –25°C to +85°C. Add $5.00

▲See page 25 for other stabilization networks.

□Model S temperature range –55°C to +125°C.

★±1nA for Model S.

⊕Requires error point clamp diodes.

Specifications subject to change without notice.

MODEL & COLOR CODE	MODEL 146 (NEW)			MODEL 180			MODEL 183			MODELS 211/210	MODEL 220			MODEL 230 (NEW)			MODEL 231 (NEW)			MODEL 232 (NEW)		
		K		J	K			K	L		J			J	K	L	J	K		J	K	
				A	B			◇	◇			B		□	□	□	□	□		□	□	
All specifications typical @ 25°C and nominal supply voltage unless otherwise specified.	LOW BIAS CURRENT FET INPUT			ULTRA LOW DRIFT DIFFERENTIAL			LOW DRIFT DIFFERENTIAL			GENERAL PURPOSE CHOPPER STABILIZED	FAST SETTLING CHOPPER STABILIZED			LOW COST CHOPPER STABILIZED			25mA OUTPUT CHOPPER STABILIZED			LOWEST COST CHOPPER STABILIZED		
OPEN LOOP GAIN																						
dc, rated load, min	10^5			3×10^5			2×10^5			10^8	10^8			10^7			10^7			10^7		
RATED OUTPUT, min	±10V @ 20mA			±10V @ 2.5mA			±10V @5mA			±10V @ 20mA	±10V @ 25mA			±10V @ 4mA			±10V @ 25mA			±10V @ 4mA		
FREQUENCY RESPONSE																						
Unity gain, small signal	5MHz			1MHz			500kHz			20MHz	10MHz/100MHz☆			500kHz			500kHz			500kHz		
Full power response, min	150kHz			10kHz			5kHz			500kHz	4MHz (peak)			3kHz			3kHz			3kHz		
Slew rate, min	10V/μsec			.6V/μsec			.3V/μsec			100V/μsec	250V/μsec			.2V/μsec			.2V/μsec			.2V/μsec		
Overload recovery	1.5msec			2msec			2msec			.2μsec	2μsec			3sec			3sec			3 sec		
INPUT OFFSET VOLTAGE @ 25°C, max, μV	±700■			see notes■●			±500■			±100★		±25★		±15★	±15★	±10★	±15★	±10★		±15★	±10★	
Average vs. temp 10 to 60°C, max, μV/°C♦		±2■		±1.5■	±.5■			±3■	±1.5■		±.5			±.25	±.25	±.1	±.25	±.1		±.25	±.1	
–25 to 85°C, max, μV/°C♦				±1.5■	±.5■			◇	◇	±1/.5▲		±.2		□	□	□	□	□		□	□	
vs. supply	±15μV/%			±2μV/%			±10μV/%			±10μV/%	±.1μV/%			±.1μV/%			±.1μV/%			±.1μV/%		
vs. time	±100μV/mo			±5μV/mo			±10μV/mo			±5μV/mo	±5μV/mo			±1μV/mo			±1μV/mo			±1μV/mo		
INPUT BIAS CURRENT @ 25°C, max	(0,–) 20pA			±4nA			(0,+) 40nA			±150/100pA	±100pA			±100pA	±50pA	±50pA	±100pA	±50pA		±100pA	±50pA	
Average vs. temp 10 to 60°C, max	doubles every 10°C			±.1/.05nA/°C			±.5nA/°C				±1pA/°C			±1/.5/.5pA/°C			±1/.5pA/°C			±1/.5pA/°C		
–25 to 85°C, max				±.2nA/°C			◇			±3/1pA/°C	±.5pA/°C			□			□			□		
INPUT DIFFERENCE CURRENT @ 25°C	±10pA			±1nA			±4nA			NA	NA			NA			NA			NA		
Average vs. temp 10 to 60°C	doubles every 10°C			±.02nA/°C			±.05nA/°C			NA	NA			NA			NA			NA		
–25 to 85°C				±.05nA/°C			◇			NA	NA			□			□			□		
INPUT IMPEDANCE																						
Differential	$10^{11}\Omega \parallel 3.5pF$			2MΩ			2MΩ			500kΩ	300kΩ @ dc⊕			300kΩ			300kΩ			300kΩ		
Common mode	$10^{11}\Omega \parallel 3.5pF$			1000MΩ			1000MΩ			NA	NA			NA			NA			NA		
INPUT NOISE																						
Voltage .01Hz to 1Hz p-p	6μV			1μV			1μV			10/5μV	3μV			1.5μV			1.5μV			1.5μV		
5Hz to 50kHz rms	16μV			4μV			12μV			10μV	4μV			5μV			5μV			5μV		
Current .01Hz to 1Hz p-p	.1pA			50pA			50pA			10pA	6pA			10pA			10pA			10pA		
INPUT VOLTAGE RANGE																						
Absolute max. differential	±15V			±15V			±15V			±15V	±15V			±15V			±15V			±15V		
Common mode voltage	>10V			>10V			>10V			NA	NA			NA			NA			NA		
Common mode rejection	10,000 @ ±5V			100,000 @ ±10V			100,000 @±10V			NA	NA			NA			NA			NA		
POWER SUPPLY	±15V @ ±5mA			±15V @ ±6mA			±15V @ ±9mA			±15V @ $^{+30}_{-4}$ mA	±15V @ ±20mA			±15V @ $^{+3}_{-6}$ mA			±15V @ $^{+8}_{-10}$ mA			±15V @ $^{+3}_{-6}$ mA		
STORAGE TEMPERATURE RANGE	–55°C to +125°C			–55°C to +85°C			–55°C to +125°C			–55°C to +85°C	–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C		
CASE STYLE (See pp. 26-29)	F-1			D-1			F-1			R-7	W-3			FA-1			WA-1			WA-1		
PRICE				A	B	J	K			211	210											
1-9	$70.			$80.	$110.	$75.	$95.			$113.	$157.	$140.	$160.		$89.	$109.	$139.	$80.	$115.		$64.	$99.	
10-24	$66.			$76.	$104.	$72.	$90.			$107.	$148.	$133.	$151.		$84.	$105.	$132.	$74.	$105.		$58.	$88.	

NOTES: *Wire pre-resistor supplied.
**Adjustable gain bandwidth. See page 25.
***Model A ±1mV, Model B ±100μV; Model J-±250μV, Model K ±100μV. Model AO available with ±250μV offset voltage. Add $5.00.
◇Models B/C available with the same specifications over the temperature range of –25°C to +85°C. Add $5.00.
▲Over the temperature range of +10°C to +85°C; ±2/1μV/°C over the temperature range of –25°C to +10°C.
□Models are available with the same specifications over the temperature range of –25°C to +85°C. Consult factory.
★Adjustable to zero.
⊕10kΩ || 3pF above 10Hz.
♦See Page 7 for explanation of measurement techniques.
Specifications subject to change without notice.

WIDEBAND / FAST RESPONSE OPERATIONAL AMPLIFIERS

MODEL & COLOR CODE	MODEL 110			MODEL 120			MODEL 121	MODEL 147			MODEL 148			MODEL 149			MODEL 211/210	MODEL 220		
																		J		
	A	B	C	A	B			A	B	C	A	B	C	A	B	C			B	
All specifications typical @ 25°C and nominal supply voltage unless otherwise specified.	INVERTING ONLY			FAST SETTLING .01% IN 1μsec INVERTING ONLY			FAST DIFFERENTIAL	HIGHEST CMRR LOW DRIFT FET			FAST SETTLING .01% IN 1μsec FET DIFFERENTIAL			FAST SETTLING .01% IN 1.5μsec FET DIFFERENTIAL			GENERAL PURPOSE CHOPPER STABILIZED	FAST SETTLING .01% IN 1μsec CHOPPER STABILIZED		
OPEN LOOP GAIN																				
dc, rated load, min	5×10^5			3×10^4			2.5×10^4	10^6			3×10^4			10^5			10^8	10^8		
RATED OUTPUT, min	±10V @ 20mA			±10V @ 25mA			±10V @ 20mA	±10V @ 10mA			±10V @ 20mA			±10V @15mA			±10V @ 20mA	±10V @ 25mA		
FREQUENCY RESPONSE																				
Unity gain, small signal	20MHz			10MHz/100MHz■			see page 25	10MHz			10MHz			15MHz			20MHz	10MHz/100MHz■		
Full power response, min	1MHz			4MHz (peak)			4MHz (peak)	150kHz			500kHz			1.5MHz◇			500kHz	4MHz (peak)		
Slew rate, min	100V/μsec			250V/μsec			250V/μsec	10V/μsec			50V/μsec			100V/μsec			100V/μsec	250V/μsec		
Overload recovery	100μsec			10μsec			.3 μsec	.4msec			5μsec			.5μsec			.2μsec	2μsec★		
INPUT OFFSET VOLTAGE @ 25°C, max	Adj to 0			Adj to 0			Adj to 0	±1mV☆			Adj to 0			Adj to 0			Adj to 0	Adj to 0		
Average vs. temp 10 to 60°C, max, μV/°C♦																		±.5		
–25 to 85°C, max, μV/°C♦	±20	±10	±5	±15	±8		± 25	±15	±10☆●	±5☆●	±50	±25	±15	±25	±15	±7	±1/.5▲		±.2	
vs. supply	±40μV/%			±20μV/%			±25μV/%	±30μV/%			±75μV/%			±20μV/%			±10μV/%	±.1μV/%		
vs. time	±250μV/mo			±50μV/mo			±100μV/mo	±100μV/mo			±250μV/mo			±250μV/mo			±5μV/mo	±5μV/mo		
INPUT BIAS CURRENT @ 25°C, max	(0,+) 30nA			(0,+) 55nA			±2μA	–30pA	–15pA	–15pA	–50pA	–25pA	–25pA	–30pA	–15pA	–15pA	±150/100pA	±100pA		
Average vs. temp 10 to 60°C, max																		±1pA/°C		
–25 to 85°C, max	±.5nA/°C			±.9/.7nA/°C			±35nA/°C	doubles every 10°C			doubles every 10°C			doubles every 10°C			±3/1pA/°C	±.5pA/°C		
INPUT DIFFERENCE CURRENT @ 25°C	±5nA			±4nA			±4μA	±10pA	±3pA	±3pA	±10pA			±10pA			NA	NA		
Average vs. temp 10 to 60°C																	NA	NA		
–25 to 85°C	.1nA/°C			±.2nA/°C			±30nA/°C	doubles every 10°C			doubles every 10°C			doubles every 10°C			NA	NA		
INPUT IMPEDANCE																				
Differential	1MΩ			200kΩ @ dc□			5kΩ ‖ 5pF	10^{11}Ω ‖ 3.5pF			10^{11}Ω ‖ 3.5pF			10^{11}Ω ‖ 3.5pF			500kΩ	300kΩ @ dc□		
Common mode	NA			NA			2MΩ ‖ 5pF	10^{12}Ω‖3.5pF			10^{11}Ω ‖ 3.5pF			10^{11}Ω ‖3.5pF			NA	NA		
INPUT NOISE																				
Voltage .01Hz to 1Hz p-p	3μV			.5μV			5μV	3μV			6μV			3μV			10/5μV	3μV		
5Hz to 50kHz rms	4μV			3μV			2μV	12μV			8μV			4μV			10μV	4μV		
Current .01Hz to 1Hz p-p	45pA			100pA			680pA	.1pA			.05pA			.05pA			10pA	6pA		
INPUT VOLTAGE RANGE																				
Absolute max. differential	±15V			±15V			±15V	±15V			±15V			±15V			±15V	±15V		
Common mode voltage	NA			NA			>10V	>10V			>10V			>10V			NA	NA		
Common mode rejection	NA			NA			5000 @ ±10V	300,000 @ ±9V			2000 @ ±9V			15,000 @ ±9V			NA	NA		
POWER SUPPLY	±15V @ ±3.5mA			±15V @ ±17mA			±15V @ ±35mA	±15V @ ±22mA			±15V @ ±5mA			±15V @ ±13mA			±15V @ $^{+30}_{-4}$ mA	±15V @ ±20mA		
STORAGE TEMPERATURE RANGE	–55°C to +125°C			–55°C to +125°C			–55°C to +100°C	–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +85°C	–55°C to +125°C		
CASE STYLE (See pp. 26-29)	Q-1			F-3			L-4	L-5			QB-1			F-1			R-7	W-3		
																	211 210			
PRICE																				
1-9	$45.	$50.	$55.	$65.	$75.		$98.	$95.	$115.	$135.	$42.	$47.	$52.	$75.	$85.	$95.	$113. $157.	$140.	$160	
10-24	$43.	$48.	$53.	$62.	$71.		$93.	$90.	$109.	$128.	$40.	$45.	$50.	$71.	$81.	$90.	$107. $148.	$133.	$151.	

NOTES: ♦See Page 7 for explanation of measurement techniques.

■Adjustable gain bandwidth. See page 25.

☆With trim resistor specified for Model B and supplied for Model C.

●Model B - ±7μV/°C and Model C - ±2μV/°C over the temperature range of +10°C to +60°C.

◇1MHz for non-inverting operation.

▲Over the temperature range of +10°C to +85°C; ±2/1μV/°C over the temperature range of –25°C to +10°C.

□10kΩ ‖ 3pF above 10Hz.

★With fast overload recovery pin connected.

Specifications subject to change without notice.

MODEL & COLOR CODE	MODEL 141			MODEL 142			MODEL 143			MODEL 144 (NEW)			MODEL 146 (NEW)			MODEL 147			MODEL 148			MODEL P501 (NEW)		
											K		J	K		•	•	•						
	A	B	C	A	B	C	A	B	C	A						A	B	C	A	B	C	A	B	C
All specifications typical @ 25°C and nominal supply voltage unless otherwise specified.	LOW COST			LOW COST 20mA OUTPUT			HIGH CMRR			LOWEST COST FET			LOW VOLTAGE DRIFT FET			BEST FET PERFORMANCE			WIDEBAND FAST SETTLING			MICROCIRCUIT FET HYBRID		
OPEN LOOP GAIN																								
dc, rated load, min	8×10^4			8×10^4			10^5			5×10^4			10^5			10^6			3×10^4			2.5×10^4		
RATED OUTPUT, min	±10V @ 2mA			±10V @ 20mA			±10V @ 20mA			±10V @ 5mA			±10V @ 20mA			±10V @ 10mA			±10V @ 20mA			±10V @ 5mA		
FREQUENCY RESPONSE																								
Unity gain, small signal	3MHz			5MHz			5MHz			4MHz			5MHz			10MHz			10MHz			4MHz		
Full power response, min	50kHz			150kHz			100kHz			100kHz			150kHz			150kHz			500kHz			70kHz		
Slew rate, min	3V/µsec			10V/µsec			7V/µsec			6V/µsec			10V/µsec			10V/µsec			50V/µsec			3V/µsec		
Overload recovery	1.4msec			1.5msec			1.5msec			100µsec			1.5msec			.4msec			5µsec			.5msec		
INPUT OFFSET VOLTAGE @ 25°C, max	Adj to 0			Adj to 0			Adj to 0			Adj to 0			±.7mV■			±1mV☆			Adj to 0			±2mV	±1mV	±1mV
Average vs. temp, 10 to 60°C, max, µV/°C◆											±30		±7■	±2■		±15●	±7●	±2●						
–25 to 85°C, max, µV/°C◆	±75	±40	±25	±50	±25	±15	±25	±15	±7	±100						±15	±10☆	±5☆	±50	±25	±15	±75	±25	±25
vs. supply	±150µV/%			±75µV/%			±20µV/%			±100µV/%			±15µV/%			±30µV/%			±75µV/%			±50µV/%		
vs. time	±250µV/mo			±250µV/mo			±250µV/mo			±250µV/mo			±100µV/mo			±100µV/mo			±250µV/mo			±250µV/mo		
INPUT BIAS CURRENT @ 25°C, max, pA	–50	–30	–30	–50	–25	–25	–30	–15	–15	(0,–) 100pA			–30	–20		–30	–15	–15	–50	–25	–25	–25	–10	–5
Average vs. temp 10 to 60°C, max										doubles every 10°C			doubles every 10°C											
–25 to 85°C, max	doubles every 10°C			doubles every 10°C			doubles every 10°C			doubles every 10°C						doubles every 10°C			doubles every 10°C			doubles every 10°C		
INPUT DIFFERENCE CURRENT @ 25°C	±10pA			±10pA			±10pA			±25pA			±10pA			±10pA	±3pA	±3pA	±10pA					
Average vs. temp 10 to 60°C										doubles every 10°C			doubles every 10°C											
–25 to 85°C	doubles every 10°C			doubles every 10°C			doubles every 10°C			doubles every 10°C						doubles every 10°C			doubles every 10°C					
INPUT IMPEDANCE																								
Differential	$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 4$pF		
Common mode	$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{12}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 3.5$pF			$10^{11}\Omega \parallel 4$pF		
INPUT NOISE																								
Voltage .01Hz to 1Hz p-p	14µV			6µV			3µV			3µV			6µV			3µV			6µV			6µV		
5Hz to 50kHz rms	10µV			16µV			8µV			3µV			16µV			12µV			8µV			6µV		
Current .01Hz to 1Hz p-p	.1pA			.1pA			.1pA			.1pA			.1pA			.1pA			.05pA			.05pA		
INPUT VOLTAGE RANGE																								
Absolute max. differential	±15V			±15V			±15V			±15V			±15V			±15V			±15V			±15V		
Common mode voltage	$^{+8}_{-10}$ V			>10V			>10V			$^{+7}_{-10}$ V			>10V			>10V			>10V			>10V		
Common mode rejection	1000 @ ±7V			2000 @ ±9V			40,000 @ ±9V			1000 @ ±5V			10,000 @ ±5V			300,000 @ ±9V			2000 @ ±9V			10,000 @ ±5V		
POWER SUPPLY	±15V @ ±4.5mA			±15V @ ±4.5mA			±15V @ ±12mA			±15V @ ±4.5mA			±15V @ ±5mA			±15V @ ±22mA			±15V @ ±5mA			±15V @ ±7mA		
STORAGE TEMPERATURE RANGE	–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C			–55°C to +125°C		
CASE STYLE (See pp. 26-29)	M-1			QB-1			TA-1			M-1			F-1			L-5			QB-1			F-1		
PRICE																								
1-9	$25.	$30.	$35.	$35.	$40.	$45.	$55.	$65.	$80.	$18.	$28.		$57.	$70.		$95.	$115.	$135.	$42.	$47.	$52.	$30.	$35.	$50.
10-24	$24.	$29.	$33.	$33.	$38.	$42.	$52.	$62.	$76.	$17.	$26.		$55.	$66.		$90.	$109.	$128.	$40.	$45.	$50.	$28.	$33.	$47.

NOTES: ◆See Page 7 for explanation of measurement techniques. ■With trim resistor specified for Model J and supplied for Model K. ☆With trim resistor specified for Model B and supplied for Model C. ●High performance over 10°C to 60°C temperature range is indicated.

Specifications subject to change without notice.

ULTRA LOW BIAS CURRENT / VARACTOR BRIDGE ELECTROMETER AMPLIFIERS

MODEL & COLOR CODE	MODEL 301	MODEL 302 A	MODEL 302 B	MODEL 303 A	MODEL 303 B	MODEL 310 (NEW) J	MODEL 310 (NEW) K	MODEL 311 (NEW) J	MODEL 311 (NEW) K
All specifications typical @ 25°C and nominal supply voltage unless otherwise specified.	HIGH PERFORMANCE DIFFERENTIAL	WIDEBAND INVERTING		WIDEBAND NON-INVERTING		LOW COST INVERTING		LOW COST NON-INVERTING	
OPEN LOOP GAIN									
dc, rated load, min	5×10^5	10^4		10^4		10^5		10^5	
RATED OUTPUT, min	±10V @ 20mA	±10V @ 2.5mA		±10V @ 2.5mA		±10V @ 5mA		±10V @ 5mA	
FREQUENCY RESPONSE									
Unity gain, small signal	500kHz	20kHz		15kHz		2kHz		2kHz	
Full power response, min	5kHz	80Hz		60Hz		7Hz		7Hz	
Slew rate, min	.3V/μsec	5V/msec		4V/msec		.4V/msec		.4V/msec	
Overload recovery	200μsec	5msec		5msec		10msec		10msec	
INPUT OFFSET VOLTAGE @ 25°C, max	Adj to 0	Adj to 0		Adj to 0		Adj to 0		Adj to 0	
Average vs. temp 10 to 60°C, max, μV/°C♦						±30	±10	±30	±10
–25 to 85°C, max, μV/°C♦	±50■	±60	±30	±60	±30				
vs. supply	±30μV/%	±100μV/%		±100μV/%		±100μV/%		±100μV/%	
vs. time	±500μV/mo	±200μV/mo		±200μV/mo		±100μV/mo		±100μV/mo	
INPUT BIAS CURRENT @ 25°C, max	±2pA	±.5pA	±.25pA	±.5pA	±.25pA	±.01pA		±.01pA	
Average vs. temp 10 to 60°C, max						doubles every 7°C		doubles every 7°C	
–25 to 85°C, max	doubles every 7°C■	doubles every 7°C		doubles every 7°C					
INPUT DIFFERENCE CURRENT @ 25°C	NA	NA		NA		NA		NA	
Average vs. temp 10 to 60°C	NA	NA		NA		NA		NA	
–25 to 85°C	NA	NA		NA		NA		NA	
INPUT IMPEDANCE									
Differential	$10^{10}\Omega \parallel 500pF$	$10^{10}\Omega \parallel 500pF$		$10^{10}\Omega \parallel 500pF$		$3 \times 10^{11}\Omega \parallel 30pF$		$3 \times 10^{11}\Omega \parallel 30pF$	
Common mode	$10^{12}\Omega \parallel 10pF$	NA		$10^{13}\Omega \parallel 3.5pF$●		NA		$10^{14}\Omega \parallel 2pF$◇	
INPUT NOISE									
Voltage .01Hz to 1Hz p-p	1μV	2μV		2μV		7μV		7μV	
5Hz to 50kHz rms	25μV	above .5Hz×.36μV/√Hz		above .5Hz×.36μV/√Hz		above 1Hz ×1μV/√Hz		above 1Hz ×1μV/√Hz	
Current .01Hz to 1Hz p-p	.01pA	.01pA		.01pA		.001pA		.001pA	
INPUT VOLTAGE RANGE									
Absolute max. differential	±20V	±75V or ±7.5mA		±75V or ±7.5mA		±300V		±300V☆	
Common mode voltage	>300V	NA		>200V		NA		☆	
Common mode rejection	10^8 @ ±300V	NA		10^6 @ ±200V		NA		100,000 @ ±25V☆	
POWER SUPPLY	±15V @ $^{+8}_{-11}$ mA	±15V @ $^{+8}_{-18}$ mA		±15V @ $^{+8}_{-18}$ mA		±15V @ $^{+15}_{-6}$ mA		±15V @ $^{+15}_{-6}$ mA	
STORAGE TEMPERATURE RANGE	–55°C to +85°C	–55°C to +85°C		–55°C to +85°C		–55°C to +85°C		–55°C to +85°C	
CASE STYLE (See pp. 26-29)	R-9	R-9		R-9		W-1		W-1	
PRICE									
1-9	$198.	$110.	$135.	$110.	$135	$75.	$125.	$75.	$125.
10-24	$193.	$105.	$128.	$105.	$128	$70.	$113.	$70.	$113.

NOTES:

■Over the temperature range of 0°C to +85°C.

☆Negative input must not exceed 25V.

●$10^9\Omega \parallel 1000pF$ for negative input.

◇$10^9\Omega \parallel 20{,}000pF$ for negative input.

♦See Page 7 for explanation of measurement techniques.

Specifications subject to change without notice.

HIGH OUTPUT CAPABILITY OPERATIONAL AMPLIFIERS

MODEL & COLOR CODE	MODEL B100	MODEL 116	MODEL 163 (NEW)		MODEL 165 (NEW)		MODEL 170	MODEL 207
				K		K		
			A		A			
All specifications typical @ 25°C and nominal supply voltage unless otherwise specified.	100mA CURRENT BOOSTER	LOW NOISE 100mA OUTPUT	20V @20mA DIFFERENTIAL		LOW COST 20V OUTPUT		100V OUTPUT DIFFERENTIAL	100V OUTPUT CHOPPER STABILIZED
OPEN LOOP GAIN								
dc, rated load, min	.85	10^5	5×10^5		2.5×10^5		10^5	10^9
RATED OUTPUT, min	±10V @ 100mA	±11V @ 100mA	±20V @ 20mA		±20V @ 5mA		±100V @ 10mA	±100V @ 10mA
FREQUENCY RESPONSE								
Unity gain, small signal		25MHz	1.5MHz		1.5MHz		3MHz	3MHz
Full power response, min	1MHz	500kHz	50kHz■		50kHz■		30kHz	30kHz
Slew rate, min		30V/μsec	6V/μsec■		6V/μsec■		18V/μsec	18V/μsec
Overload recovery		.2μsec	.5msec		.5msec		200μsec	.5μsec
INPUT OFFSET VOLTAGE @ 25°C, max	±200mV	±10mV	Adj to 0		Adj to 0		±5mV	±20μV
Average vs. temp 10 to 60°C, max, μV/°C♦				±5		±5		
–25 to 85°C, max, μV/°C♦	±1mV/°C	±100	±20		±20		±20	±.2
vs. supply	NA	±500μV/%	±10 μV/%		±10μV/%		±5μV/%	±1μV/%
vs. time		±250μV/mo	±200μV/mo		±200μV/mo		±250 μV/mo	±5μV/mo
INPUT BIAS CURRENT @ 25°C, max	±500μA	±300nA	(0,+) 35nA		(0,+) 35nA		(0,+) 150nA	±50pA
Average vs. temp 10 to 60°C, max, nA/°C			±.5nA/°C		±.5nA/°C			
–25 to 85°C, max, nA/°C	NA	±40nA/°C	±.6nA/°C		±.6nA/°C		±1.5nA/°C	±.5pA/°C
INPUT DIFFERENCE CURRENT @ 25°C	NA	±300nA	±3nA		±3nA		±20nA	NA
Average vs. temp 10 to 60°C, nA/°C	NA		±.05		±.05			NA
–25 to 85°C, nA/°C	NA	±5nA/°C	±.1		±.1		±.5nA/°C	NA
INPUT IMPEDANCE								
Differential	9kΩ	20kΩ	1MΩ		1MΩ		150kΩ	220kΩ
Common mode	NA	5MΩ	1000MΩ		1000MΩ		100MΩ	NA
INPUT NOISE								
Voltage .01Hz to 1Hz p-p	NA	2μV	1μV		1μV		3μV	10μV
5Hz to 50kHz rms	NA	2μV	3μV		3μV		3μV	10μV
Current .01Hz to 1Hz p-p	NA	300pA	20pA		20pA		500pA	20pA
INPUT VOLTAGE RANGE								
Absolute max. differential	±15V	±15V	±40V		±40V		±20V	±15V
Common mode voltage	NA	>10V	>20V		>20V		>20V	NA
Common mode rejection	NA	10,000 @ ±10V	20,000 @ ±20V		20,000 @ ±20V		40,000 @ ±20V	NA
POWER SUPPLY	±15V @ ±8mA	±15V @ ±14mA	±24V @ ±2mA		±24V @ ±4mA		±120V @ ±6mA	±120V @ ±7mA
STORAGE TEMPERATURE RANGE	–55°C to +125°C	–55°C to +125°C	–55°C to +125°C		–55°C to +125°C		–55°C to +125°C	–55°C to +85°C
CASE STYLE (See pp. 26-29)	Q-1	T-10	F-1		M-1		T-10	B-7
PRICE								
1-9	$30.	$98.	$36.	$46.	$24.	$34.	$125.	$235
10-24	$29.	$95.	$34.	$43.	$20.	$29.	$119.	$224

NOTES:

■10kHz and 1.2V/μsec for non-inverting operation.

♦See Page 7 for explanation of measurement techniques.

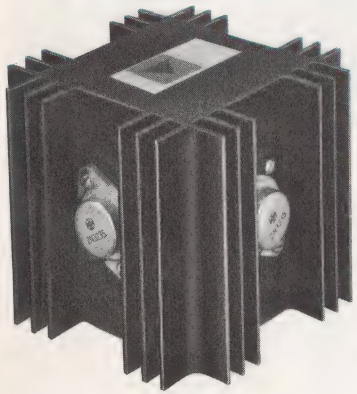
Specifications subject to change without notice.

STILL AVAILABLE

The products shown here can no longer be recommended as "best values" from a price/performance viewpoint. With the knowledge that these "old favorites" are performing their assigned functions in literally thousands of applications, this listing is provided as a specification reference. Of course, all of these amplifiers are still available at the prices indicated.

DESCRIPTION Specification Typical at +25°C and nominal supply voltages.	MODEL	OPEN LOOP GAIN	RATED OUTPUT		FREQUENCY RESPONSE			OFFSET VOLTAGE	BIAS CURRENT		INPUT Z		CASE STYLE	PRICE
		V/V min	Volts min	mA min	Unity Gain MHz typ	Full Power kHz min	Slew Rate V/μs min	vs. temp. μV/°C max	@ 25°C nA max	vs. temp. nA/°C max	Diff. MΩ typ	CM MΩ typ		$ (1–9)
Lowest Cost - $13	111	15k	±10	2.5	1.5	30	1.8	±20	(0,+)200	± 2	.2	50	M–1	$13
Moderate Gain, 2.5mA	105A/B/C	30k	±10	2.5	2	20	1.2	±20/10/5	(0,+)50	± .7	1	100	M–1	$16/21/26
High Gain, 5mA	106A/B/C	250k	±10	5	2	20	1.2	±20/10/5	(0,+)50	± .7	1	100	Q–1	$21/26/31
106 with Reduced Bias Current	107A/B/C	250k	±10	5	2	20	1.2	±20/10/5	± 5	± .9	1	100	Q–1	$24/29/34
Low Bias Current, High Z, 2.5mA	108A/B/C	100k	±10	2.5	.5	2	.12	±20/10/5	± 2	± .15	4	500	Q–1	$28/33/38
Stabilized 6dB/oct. Small Volume	203	100M	±10	20	2	20	1.2	±.2	± .05	±.0005	.22	–	R–6	$215
Stabilized, 100mA Output	201	1000M	±10	100	10	500	30	±.2	± .05	±.0005	.22	–	R–6	$235
General Purpose, Diff.	102A/B/C	2M	±10	20	10	300	30	±20/10/5	± 2	± .2	6	500	L–5	$95/105/120
Low Cost, 20V @ 2.5mA	160	250k	±20	2.5	1.5	10	1.2	±20	± 5	± .9	1	100	Q–1	$40
Gen. Purpose, 20V @ 10mA	161	250k	±20	10	1.5	10	1.2	±20	± 5	± .9	1	100	L–4	$65
Wideband, 250mA	117	100k	±11	250	25	500	30	±100	± 300	± 40	.02	5	T–10	$148
Moderate Bandwidth, 20mA	109A/B/C	250k	±10	20	2	20	1.2	±20/10/5	± 5	±.9	1	100	L–4	$42/47/52

POWER AMPLIFIER



FEATURES

Output Power – 40 watts
Bandwidth – DC to 10kHz
Single Supply Voltage – 28 VDC
Current Limited Output – 2 amps
Short Circuit Protected

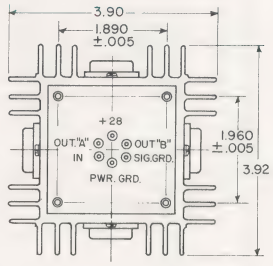
SPECIFICATIONS

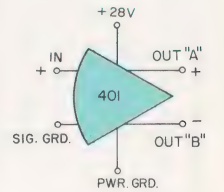
(@25°C, +28 VDC and 16 ohm load unless noted)

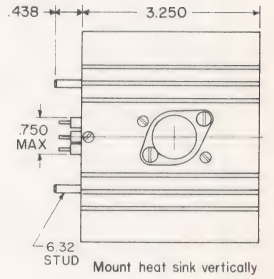
Output Power	40 watts
Output Voltage*	±24V for 16 ohm load
Output Current, max*	±2 amps (current limited) ±1.5 amps (short circuit)
Load Impedance	10 ohms, min
Linearity	±1% up to 22V
Input Impedance, min	25k ohms
Input Current, max	60μa
Input Voltage, max	±25V
Zero Offset, max	±10mV
Input Offset Drift	0.25mV/°C
Source Impedance, max	500 ohms
Supply Voltage Coupling	0.5mV/V
Gain	20V/V±5%
Gain Stability	±3% (–45 to +70°C)
Bandwidth (3dB)	10kHz
Power Supply Voltage	24 to 32 VDC
Operating Temperature	–45 to +70°C
Price (1-9)	$275.

*Neither output can be connected to power supply ground.

OUTLINE DIMENSIONS







Mount heat sink vertically

MILITARY APPLICATIONS

Many of the standard products offered by Analog Devices have been supplied to meet the reliability and other requirements of military and space programs. Because of the large variability in cost resulting from the types of components that are used, and the amount of environmental tests which are performed, these are nearly always treated as special products.

In general, our standard products will meet military specs with no modifications. The inherent construction of encapsulated op amps insures immunity to humidity, salt spray, fungus, dust and other environmental conditions. These amplifiers will also survive extremely high levels of shock and vibration since the components are rigidly held in epoxy. The components themselves have ratings exceeding military temperature requirements, and most amplifiers can be made to operate over these extremes.

To verify the reliability of our standard products, ten samples each of 16 different standard amplifier types were recently submitted to extensive qualification tests. These tests were conducted in accordance with Mil–Standard 202C and the following methods: Shock–Method 202; Vibration–Method 204; Thermal Shock–Method 102; Moisture Resistance–Method 106; High Temperature Range–Method 108; and Steady State Operating Life–Method 108. The above test reports will be sent to you on request. Additionally, stress analyses and MTBF reliability predictions in accordance with Mil Handbook 217A are available for virtually all of our amplifiers.

The largest decision in modifying standard products for military applications relates to the choice of parts. In this regard, our standard products liberally use epoxy type transistors, which are not approved for use in some programs. At additional cost, hermetically sealed metal case transistors can be substituted. Here you may choose JAN approved, QPL approved, or "burned in" components. Another factor which can substantially affect price and delivery is the amount of performance and environmental testing which must be performed. We recommend that you consult with our applications group to establish the most economical test plan for your particular application.

Quality control procedures at Analog Devices conform to MIL-Q-9858A. Equipment for vacuum encapsulation is available. Our reliability specialists are experts in mil specifications and procedures. They are anxious and able to discuss these requirements with you.

CUSTOM DESIGN PRODUCTS

It should be realized that there is usually a considerable latitude in available specifications of our standard products. Our "standard products" are those which are built to our published specifications. Specials are those which are built or selected for a particular customer order. The specifications which we choose to publish for standard products represent our estimate of the best overall design compromise. Often very minor changes in component values can effect design trade-offs to make a more economical amplifier for any given application.

Here are some considerations to guide your thinking about specials:

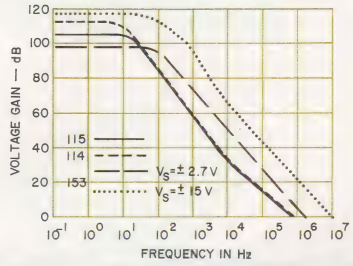
1. The simplest kind of special is one where tighter specifications or additional specifications are guaranteed by selection in final test. For example, voltage and current drift can be tested and specified over extended temperature ranges, or common mode rejection (which is normally given as a typical specification) can be selected to give a guaranteed minimum which is better than the typical published spec. These kinds of specials require no drawing changes except for the final test plan so that increased cost and delivery time are minimal.

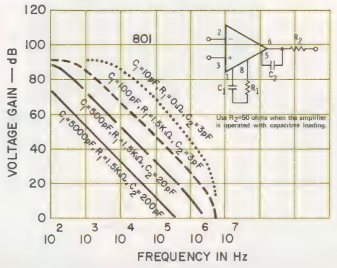
2. The next level of complexity in supplying specials is to alter or select the component values of a standard amplifier without changing the design configuration. This usually requires changes in production drawings and the cost is amortized over the quantity ordered. Examples of such modifications might be: to increase output current rating at the expense of higher quiescent current (or vice versa); to increase bandwidth or slewing rate at the expense of increased bias current drift (or vice versa); etc. Delivery with such modifications is somewhat extended.

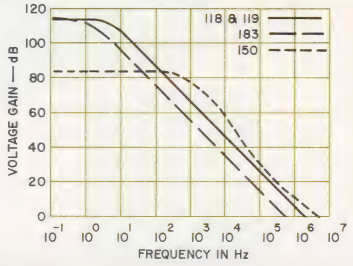
3. The most difficult, time consuming and expensive specials are those which involve dimensional and pin configuration changes, which involve changes of the internal printed circuit board, or circuit changes which involve engineering unknowns. Even so, for large quantity procurements it may be more economical to invest in Analog Devices' custom engineering than to buy more performance than you need. In any case, please consult with our Application Engineering Department.

OPEN LOOP RESPONSE CHARACTERISTICS

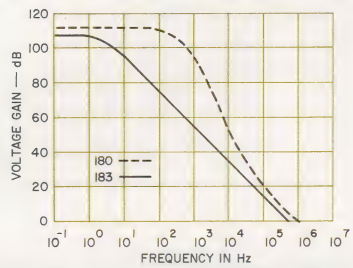
LOW COST/MODERATE PERFORMANCE

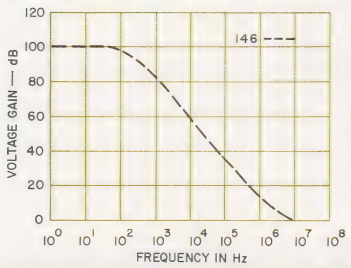


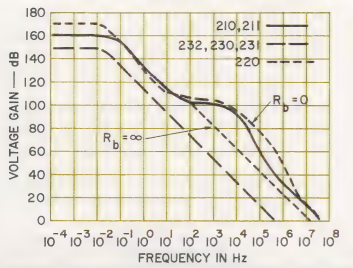




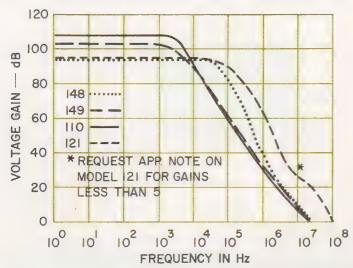
LOW VOLTAGE DRIFT

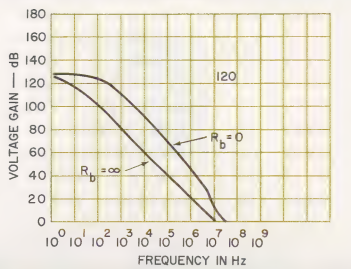


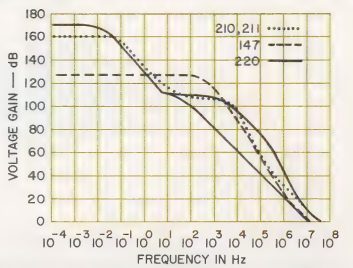




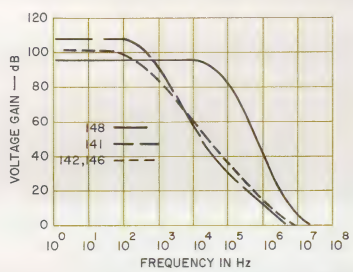
WIDEBAND/FAST RESPONSE

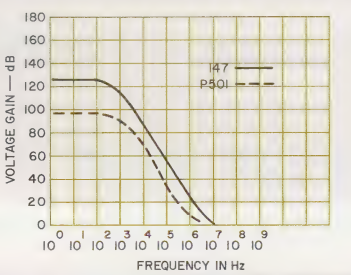


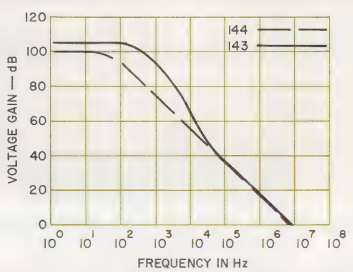




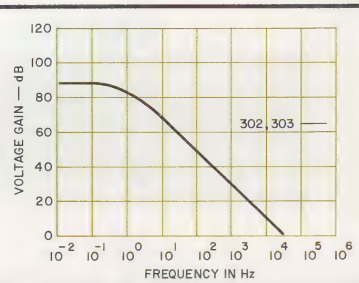
LOW BIAS CURRENT/FET INPUT

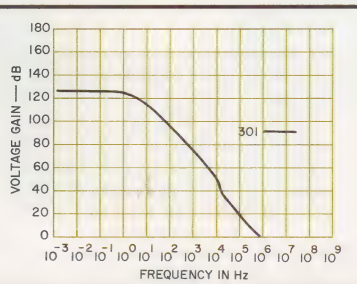


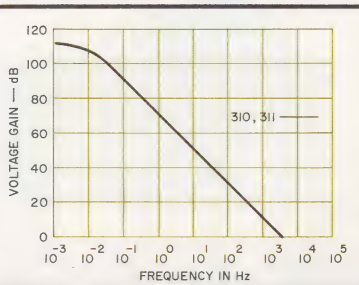




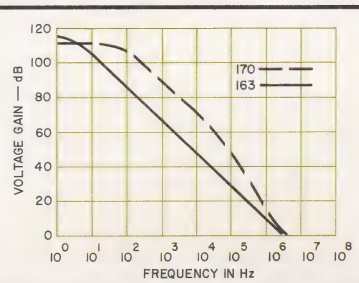
ULTRA LOW BIAS CURRENT/VARACTOR BRIDGE

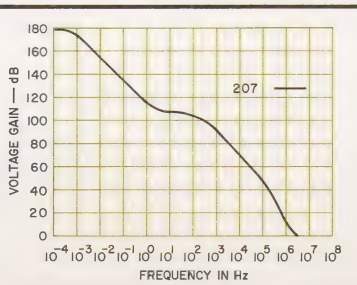


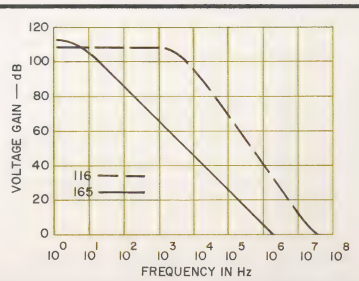




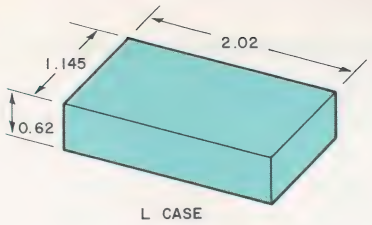
HIGH OUTPUT CAPABILITY



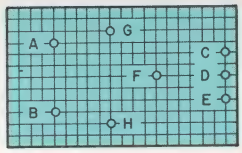




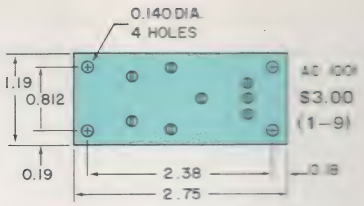
L



L CASE



L-4,L-5

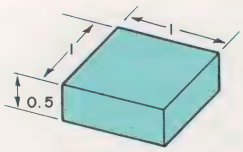


(L–4) (L–5)

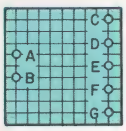
MODEL	CASE STYLE	PIN A	B	C	D	E	F	G	H	EXT. POT/RES. Across	Arm	Value
121	L–4	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out	Pot	Pot	G–H	C	5kΩ
147	L–5	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out	Pot	Pot	G–H	G	10kΩ*
701	L–4	IN	Sig. Ret.	$+V_S$	Com	$-V_S$	Out	Pot	Pot	G–H	C	250kΩ
114	L–4	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out	Pot	Pot	G–H	C	250kΩ
109, 161	L–4	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out	Pot	Pot	G–H	C	50kΩ
102	L–5	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out	Pot	Pot	G–H	G	50kΩ

*For Model 147C use resistor provided with amplifier. For Model 147B use 4.99k 1% metal film.

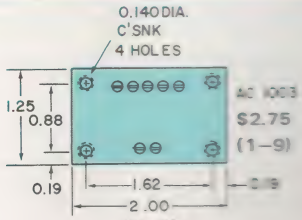
M



M CASE



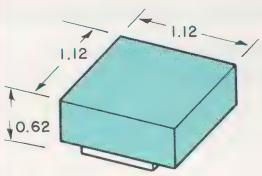
M-1



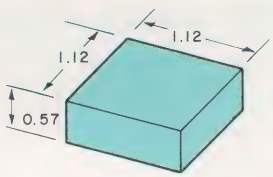
(M–1)

MODEL	CASE STYLE	PIN A	B	C	D	E	F	G	EXT. POT/RES. Across	Arm	Value
141, 144	M–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G	C	1kΩ
105, 111, 118, 165	M–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G	C	50kΩ
115	M–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G	C	250kΩ

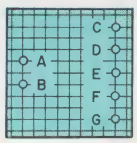
Q



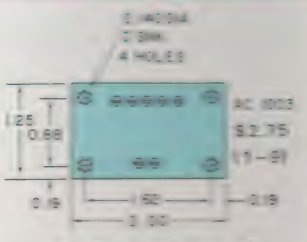
Q CASE



QB CASE



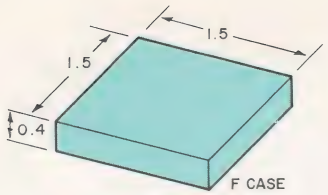
Q-1, QB-1, Q-2

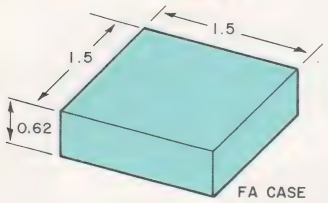


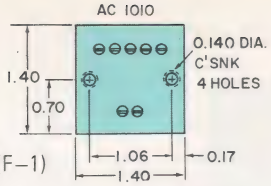
(Q–1) (Q–2) (QB–1)

MODEL	CASE STYLE	PIN A	B	C	D	E	F	G	EXT. POT/RES. Across	Arm	Value
106, 107 150, 160	Q–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G	C	50kΩ
108	Q–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G	C	250kΩ
110	Q–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G	C	100kΩ
180	Q–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G		*
B100	Q–2	NC	IN(+)	$+V_S$	Com	$-V_S$	Out+	NC			
142, 148	QB–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim	C–G	C	1kΩ

* Use fixed resistor provided with amplifier.

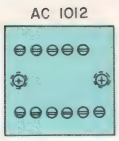






(F–1)

(FA–1) **$3.00 (1–9)**

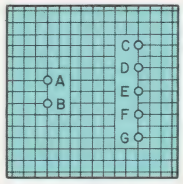


(FA–2)

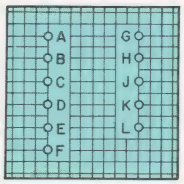
$4.00 (1–9)

(F–3)

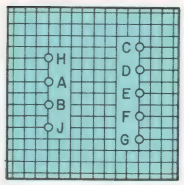
$3.50 (1–9)



F-1,FA-1



FA-2

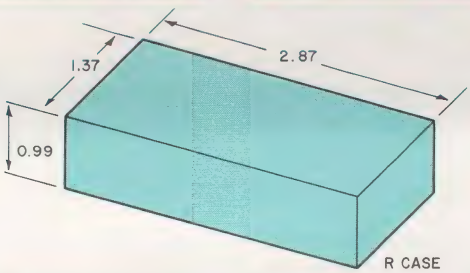


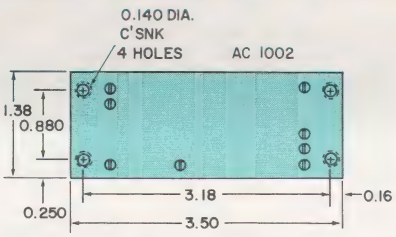
F-3

MODEL	CASE STYLE	PIN A	B	C	D	E	F	G	H	J	K	L	EXT. POT/RES. Across	Arm	Value
183	F–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim					C–G		*
149	F–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim					E–G	E	1kΩ
119, 163	F–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim					C–G	C	50kΩ
146	F–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim					C–G	C	* ♦
350	F–1	IN(–)	IN(+)	$+V_S$	Limit	$-V_S$	Out+	Trim					C–G	C	1kΩ
143	FA–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim					E–G	E	2kΩ
230	FA–1	IN(–)	SG	$+V_S$	Com	$-V_S$	Out+	Trim					C–E	G	100kΩ
420, 421	FA–2	$+V_R$	X Zero	X	Y	Y Zero	$-V_R$	$+V_S$	Com	$-V_S$	Out	Out Zero	A–F A–F A–F	B E L	20kΩ 20kΩ 20kΩ
602	FA–2	IN(–)	IN(+)	Shield Drive	Gain Com	Gain Adj.	NC	$+V_S$	Com	$-V_S$	Out	Bal	G–L	G	10kΩ
120	F–3	IN(–)	SG	$+V_S$	Com	$-V_S$	Out+	Trim	BW	NC			C–G H–A	C	100kΩ Optional Short
153	F–1	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out+	Trim					C–G		*

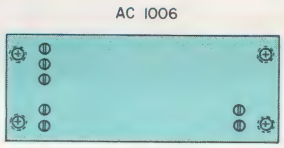
♦For Model J use 4.99Ω 1% metal film. * Use fixed resistor provided with amplifier.

F

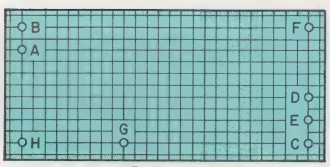




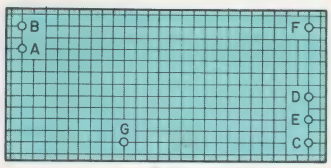
(R–6) (R–7) **$3.50 (1–9)**



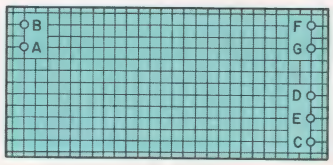
(R–9) **$3.75 (1–9)**



R-6



R-7

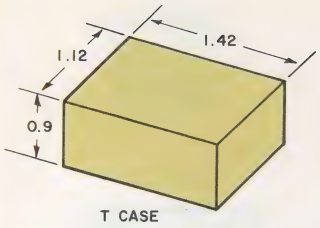


R-9

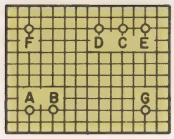
R

MODEL	CASE STYLE	PIN A	B	C	D	E	F	G	H	EXT. POT/RES. Across	Arm	Value
201, 203	R–6	IN(–)	Sig. Ret.	$+V_S$	Com	$-V_S$	Out	Fast Rec.	NC			
207	R–7	IN(–)	Sig. Ret.	$+V_S$	Com	$-V_S$	Out	Fast Rec.				
210, 211	R–7	IN(–)	Sig. Ret.	$+V_S$	Com	$-V_S$	Out	Bal		E–C	G	50kΩ
301,302,303	R–9	IN(–)	IN(+)	$+V_S$	Com	$-V_S$	Out	Bal		D–G	D	1kΩ

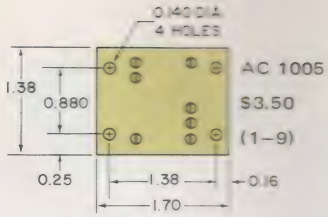
T



T CASE



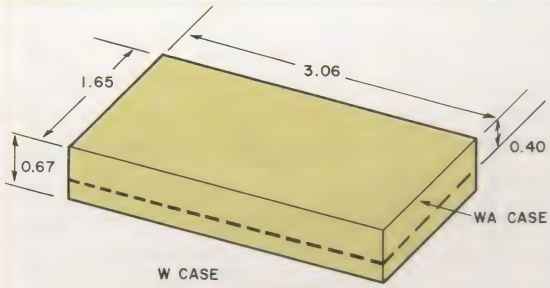
T-10



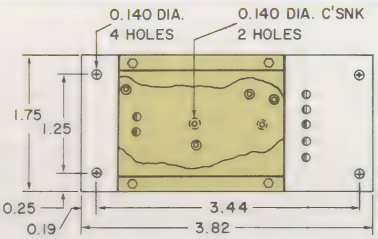
(T–10)

MODEL	CASE STYLE	PIN A	B	C	D	E	F	G	EXT. POT/RES. Across	Arm	Value
116, 117, 170	T–10	IN(–)	IN(+)	$-V_S$	Com	$+V_S$	Out	NC			

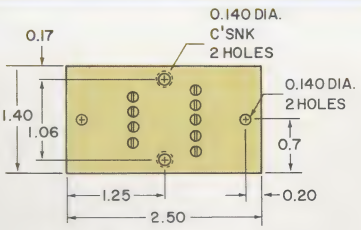
W



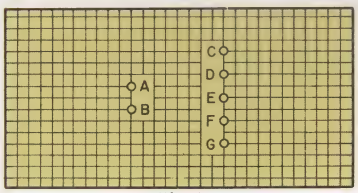
W CASE



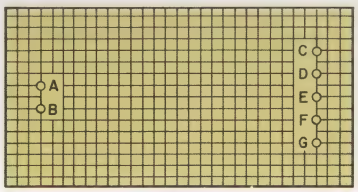
AC 1017 **$6.00 (1–9)**
(W–1)



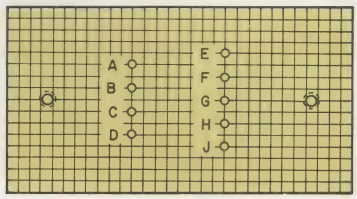
AC 1014 **$3.50 (1–9)** (WA–1)
(W–3)



WA–1



W–1



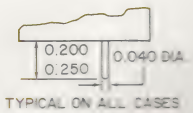
W–3

MODEL	CASE STYLE	PIN A	B	C	D	E	F	G	H	J	EXT. POT/RES. Across	Arm	Value
220	W–3	BW	IN(–)	SG	FR	$+V_S$	Com	$-V_S$	Out	Trim	E–G	J	100kΩ
310	W–1	IN(–)	Sig. Ret.	$+V_S$	Com	$-V_S$	Out	Trim			C–E	G	100kΩ
311	W–1	IN(+)	Sig. Ret.	$+V_S$	Com	$-V_S$	Out	Trim			C–E	G	100kΩ
231, 232	WA–1	IN(–)	Sig. Ret.	$+V_S$	Com	$-V_S$	Out	Trim			C–E	G	100kΩ

GENERAL NOTES ON MECHANICAL DATA.

All base and socket diagrams are bottom views.

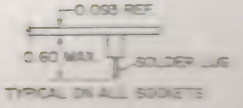
Pin letters are for reference only and do not appear on cases. (In general, pin designations are silk-screened on sockets.)



TYPICAL ON ALL CASES

Grids shown on base views are 0.10 interval, and for reference only.

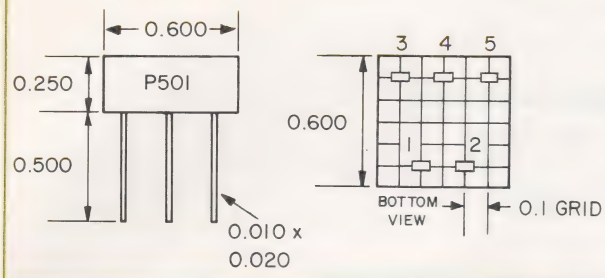
Socket material is Nema grade G-10 glass epoxy.



TYPICAL ON ALL SOCKETS

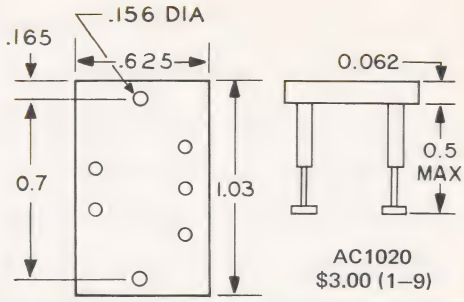
Pins are gold plate, half-hard brass.

P501 (P-CASE)



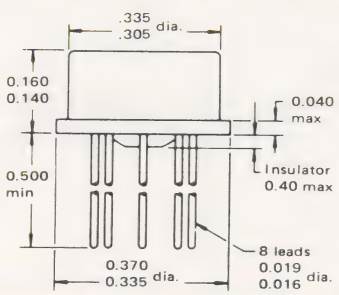
PIN CONNECTIONS

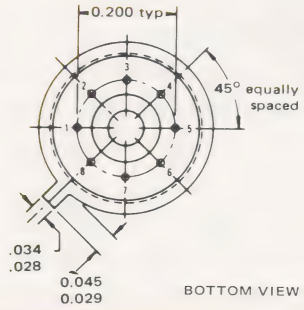
PIN 1: INVERTING INPUT
PIN 2: NON-INVERTING INPUT
PIN 3: +15VDC
PIN 4: −15VDC
PIN 5: OUTPUT

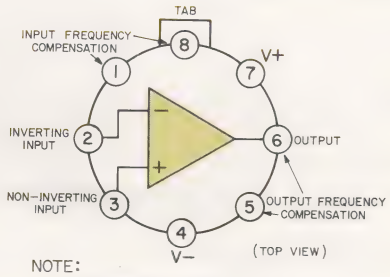


AC1020
$3.00 (1–9)

801 (TO-99 CASE)

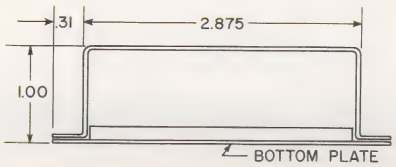




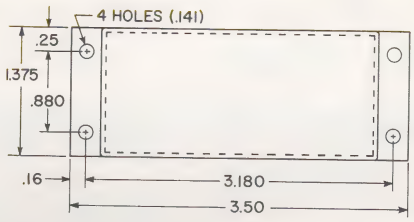


NOTE:
PIN 4 CONNECTED TO CASE

NOISE SHIELD



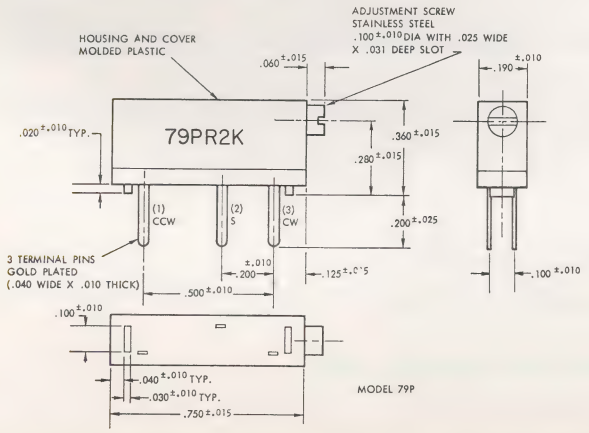
AC1106
$7.00 (1–9)



May be used with any R case style amplifiers to provide electrostatic shielding.

MODEL 79P CERMET BALANCE POT

Analog Devices has selected the Beckman Helitrim Model 79P as suitable for most applications and carries this balance pot in stock. We offer this service since you may find it more economical or convenient to order your balance pots directly from Analog Devices along with your amplifiers. The identical pots are also available from Beckman or their stocking distributors.



SPECIFICATIONS

Tempco, max.	±100ppm (0 to-250ppm for 250k ohms)
Input voltage, max.	200VDC or RMS
Power rating	0.75 watts at +25°C, derated to 0 watts at +105°C
End resistance, max.	2 ohms
Resolution	essentially infinite
Ambient temperature range	−55°C to +105°C
Adjustment turns, nominal	15
Sealing (immersion test)	meets MIL-R-22097C
Temperature cycling	5 cycles−55°C to +105°C
Humidity cycling	5 cycles
Shock	50G's
Vibration	10 to 500kz, 10G's
Load life at 0.75 watts	1,000 hrs. at +25°C
Rotational life	200 cycles

ANALOG DEVICES PART NUMBER	RESISTANCE OHMS	PRICE
79PR1k	1k±10%	(1–9) − $3.00
79PR2k	2k±10%	(10–99) − 2.75
79PR10k	10k±10%	(100–249) − 2.50
79PR50k	50k±10%	
79PR100k	100k±10%	
79PR250k	250k±10%	

BIBLIOGRAPHY OF OPERATIONAL AMPLIFIER PUBLICATIONS

RCA Linear Integrated Circuit Fundamentals

Radio Corporation of America, Harrison, New Jersey

A lengthy treatment of op-amp theory with applications slanted towards linear integrated circuits of RCA origin. (240 pages)

Handbook of Operational Amplifier Applications

Burr-Brown Research Corporation, Tucson, Arizona

A good basic introduction to op-amp theory for the beginner plus a liberal collection of typical circuits. (84 pages)

Handbook of Operational Amplifier Active RC Networks

Burr-Brown Research Corporation, Tucson, Arizona

An elementary treatment of op amps in active filter circuits. (104 pages)

Applications Manual

Philbrick/Nexus, A Teledyne Co., Dedham, Massachusetts

A 115-page manual which every op-amp user should own. About one-third of the book is devoted to op-amp theory while the balance gives a valuable assortment of typical op-amp circuits.

Electronic Analog and Hybrid Computers, Korn & Korn, 1964

McGraw Hill Book Company, 330 West 42nd Street, New York, New York

A textbook mainly on analog computers, but with a great deal of useful information on op-amp circuits. (584 pages)

Linear Integrated Circuits Applications Handbook

Fairchild Semiconductor, 313 Fairchild Drive, Mountain View, California

A prolific publication to "provide significant insight into the advantage and limitations inherent monolithic construction and how these relate to specific systems (and circuit) design problems, a serve as a convenient reference for all users of linear integrated circuits." Many applications ideas. (188 pages)

Operational Amplifiers—Principles of Operation and Analysis of Errors - Parts I, II, IV

Analog Devices, Inc., Cambridge, Massachusetts

A three part series with greater depth in the discussion of op-amp theory than is found in most publications. Part I analyzes the sources of error resulting from non-ideal characteristics of op amps. Part II discusses advantages and disadvantages of the three op amp configurations. Part IV goes into detailed discussion of the greatest source of error in op amps—offset and drift. (22 pages)

Advantages of 12dB/Octave Operational Amplifiers and Their Application

Analog Devices, Inc., Cambridge, Massachusetts

Brief discussion of advantages of fast roll-off amplifiers in fast response applications as well as techniques for beating the stability problems. (6 pages)

Evolution from Operational Amplifier to Data Amplifier

Analog Devices, Inc., Cambridge, Massachusetts

A 36-page booklet which explains the difference between op amps and data amplifiers. Theory, circuits and specifications of each are included.

Analog Dialogue

Analog Devices, Inc., Cambridge, Massachusetts

A periodic journal devoted to technical discussions of operational amplifier theory and practice.

Comprehensive Data Sheets and Application Notes

Analog Devices, Inc., Cambridge, Massachusetts

Currently available on most products.

ANALOG DEVICES PUBLICATIONS

Analog Devices places heavy emphasis on publishing technical literature which is truly useful to engineers engaged in the application of our products. Particular attention is given to the descriptive literature which is available for nearly all of our currently produced amplifiers. More comprehensive than ordinary data sheets, these individual brochures include application considerations, schematic diagrams, graphs of circuit performance characteristics, and complete listings of specifications for all pertinent parameters. In most cases, and particularly with regard to new or specialized devices, definitions of specifications and background technical information is also given. Each of these data sheets is designed to provide all information required to accurately characterize the device and thus insure a proper and straightforward circuit design.

In addition to these individual data sheets, a number of publications are available which offer both theoretical and practical reference material for using and understanding operational amplifiers. Special applications are covered in a series of detailed application notes. "Analog Dialogue," our highly popular journal devoted to "the exchange of information pertaining to analog technology" is produced quarterly and sent without charge to qualified engineers. Articles chosen for publication are those which illustrate new or novel devices and/or application techniques and are usually of broad interest.

Any of this literature is available to you free of charge upon request and is, for the most part, stocked at all representative offices.

APPLICATIONS ENGINEERING SERVICES

A team of highly trained op-amp specialists is maintained to provide a consultation service to engineers designing with operational amplifiers.

These experts can analyze your requirements, suggest circuit designs, and recommend hardware suitable to your application. Extensive files of application designs are kept, and valuable hours of your design time can often be saved by a simple phone call or letter to our Applications Engineering Department.

Address correspondence to:
Applications Engineering Department
Analog Devices, Inc.
221 Fifth Street
Cambridge, Massachusetts 02142
Or telephone collect (617) 492-6000 (TWX) 710/320-0326
and ask for the Applications Engineering Department

All inquiries will be answered promptly.

This service is intended to promote the effective and economical application of our products and is provided without cost or obligation.

SALES OFFICES

ANALOG DEVICES, INC.
221 Fifth Street
Cambridge, Mass. 02142
TEL: 617/492-6000
TWX: 710/320-0326

LABTRONICS, INC.
Kingston, New York 12401
TEL: 914/338-1604

3568 Moyer Road
North Tonawanda, New York 14120
TEL: 716/695-1001

130 Pickard Building, Rm. 130
East Molloy Road
Syracuse, New York 13211
TEL: 315/454-9314

HARWOOD–SANDLER ASSOCIATES
8243 Jericho Turnpike
Woodbury, L.I., New York 11797
TEL: 516/692-6100

ELECTRO SALES ASSOCIATES
Overlook Branch
Box 3122
Dayton, Ohio 45431
TEL: 513/426-5551

10745 Morang Drive
Detroit, Michigan 48224
TEL: 313/886-2280

851 East 222nd Street
Cleveland, Ohio 44123
TEL: 216/261-5440

201 Penn Center Boulevard
Pittsburgh, Pennsylvania 15235
TEL: 412/371-9449

IMPALA, INC.
3141 Merriam Lane
Kansas City, Kansas 66106
TEL: 913/831-3933

47 Village Square
Room 3
Hazelwood, Missouri 63042
TEL: 314/831-5454

AVIONICS LIAISON
6770 Perimeter Road, South
Seattle, Washington 98108
TEL: 206/ 767-3870
TWX: 910/444-2013

SYSTEMS ENGINEERING ASSOCIATES
1010 East 86th Street
Indianapolis, Indiana 46240
TEL: 317/846-2593

5505 North Menard Avenue
Chicago, Illinois 60630
TEL: 312/774-1452

8633 Harrison, South
Minneapolis, Minnesota 55431
TEL: 612/881-6386

P.O. Box 526
Waukesha, Wisconsin 53186
TEL: 414/782-3388

BARNHILL ASSOCIATES, INC.
3810 Westheimer, Suite 332
Houston, Texas 77027
TEL: 713/621-0040
TWX: 910/881-2573

312 North Central Expressway
Suite 220
Richardson, Texas 75080
TEL: 214/231-2573
TWX: 910/861-4711

1170 South Sheridan Boulevard
Denver, Colorado 80226
TEL: 303/934-5505
TWX: 910/931-2685

827 Pennsylvania, N.E.
Albuquerque, New Mexico 87110
TEL: 505/265-7766
TWX: 910/989-1650

4900 East Indian School Road
Phoenix, Arizona 85018
TEL: 602/959-2115
TWX: 910/950-1283

REP–TRON, INC.
P.O. Box 1347
Silver Spring, Maryland 20902
TEL: 301/588-6933

SYNERGEN, INC.
4868 Oak Park Avenue
Encino, California 91316
TEL: 213/981-4150

201 Town and Country Village
Palo Alto, California 94301
TEL: 415/328-3383

WYNCOTE INSTRUMENTATION
1616 Kenmare Drive
Dresher, Pennsylvania 19025
TEL: 215/643-2440

CURRIE AEROSPACE ASSOCIATES
2907 McCoy Road
P.O. Box 13229
Orlando, Florida 32809
TEL: 305/855-0843
TWX: 810/850-0106

2603 Artie Street, S.W.
Suite 15
P.O. Box 1424
Huntsville, Alabama 35807
TEL: 205/536-5650
TWX: 810/726-2200

614 Nissen Building
Winston-Salem, North Carolina 27101
TEL: 919/725-1927

FACTORY DIRECT

C A N A D A

WHITTAKER ELECTRONICS, LTD.
42 Howden Avenue
Ottawa 5, Ontario, Canada
TEL: 613/224-1221
TWX: 610/562-1920

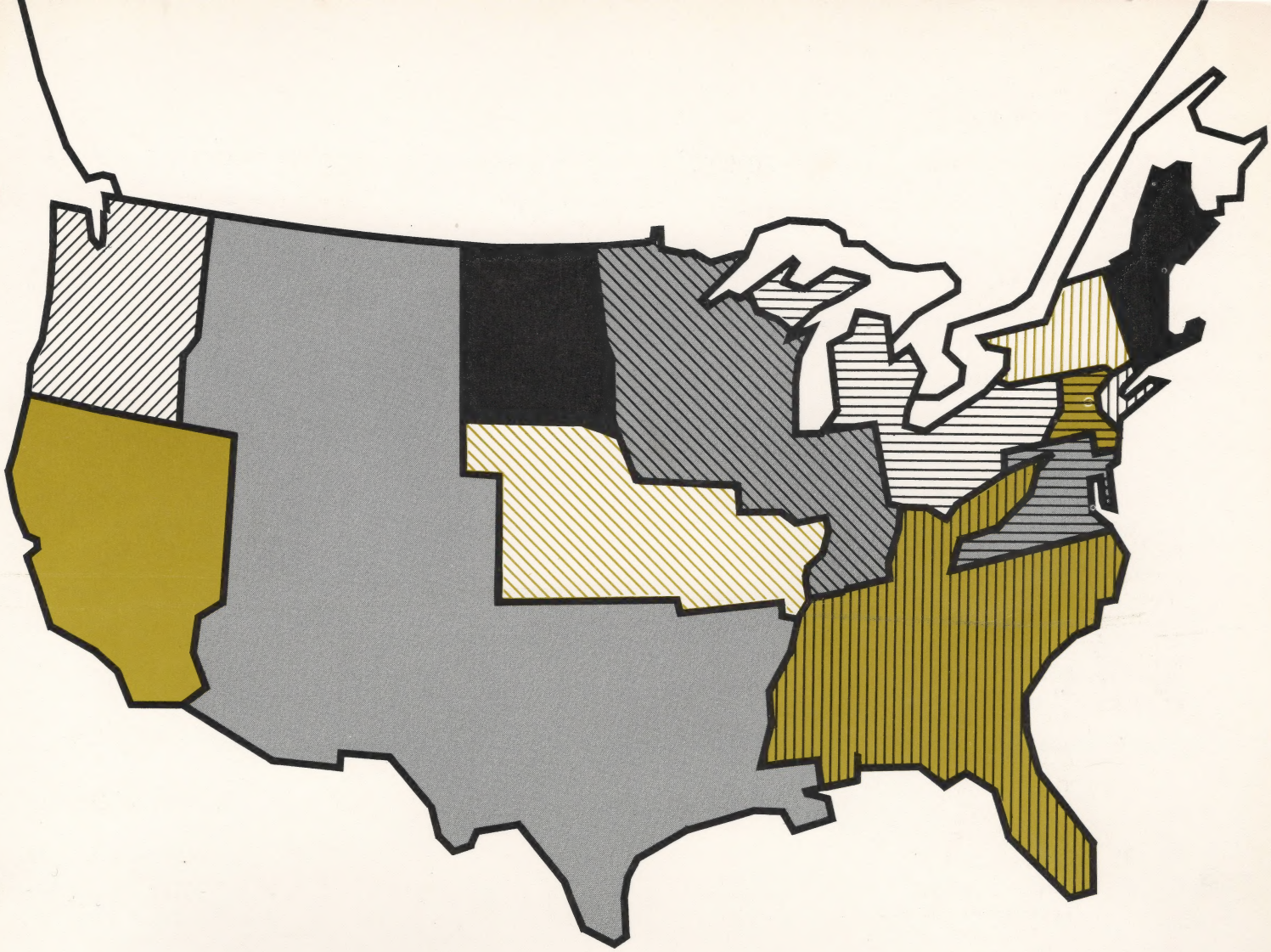
1144 Millstream Road
West Vancouver, B.C., Canada
TEL: 604/926-3411 and Zenith 1-9240
TWX: 610/924-6033

P.O. Box 216
Roxboro, Quebec, Canada
TEL: 514/683-3621
TWX: 610/422-3980

1885 Wilson Avenue
Weston, Ontario, Canada
TEL: 416/247-7454
TWX: 610/492-2383

The Representatives listed above have been carefully selected and trained to be of genuine assistance to you in the selection and application of operational amplifiers. They are anxious and able to provide comprehensive Analog literature, evaluation samples of our products, and a direct communication link with our Application Engineering Department (see page 31).

We are proud of the high calibre of our representatives and sincerely encourage you to contact them for immediate and professional assistance.



HERE IS YOUR ***INSTANT ACTION SERVICE SYSTEM*** REGISTRATION CARD

Please use it each time you wish to request:

- Comprehensive data sheets
- Evaluation samples
- Applications assistance
- A change of address

Use of this card will help us to provide fast, accurate response to your inquiry.

Each time you use the card a replacement will be sent along with the requested material.

ANALOG DEVICES INC

221 5th Street • Cambridge • Massachusetts 02142 • (617) 492-6000